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Letter from the Editor

This issue will be my last as Editor of the Journal of the Washington Academy of Sciences. For more than two years, I've enjoyed working with the various authors, the Discipline Editors, and the Board. Most importantly, I could not have gotten any of these issues published without the dedication of the Associate Editor, Sethanne Howard. I want to thank everyone for welcoming me and working with me during my tenure as editor.

We are fortunate to have Dr. Sally Rood taking over the position of editor. I have no doubt that she will continue the excellence of this publication and I look forward to seeing her contributions to the Journal. For my final issue, I am happy to present four articles that are a product of CapSci 2012. They embody the diversity of this organization and showcase some of our talented members.

First, we present *Anomaly Detection for Insulated Gate Bipolar Transistor (IGBT) under Power Cycling using Principal Component Analysis and K-Nearest Neighbor Algorithm* by E. Sutrisno *et al.* We move from there to *Simulation-based Military Training: An Engineering Approach to Better Addressing Competing Environmental, Fiscal, and Security Concerns* by Jason E. Summers. We then shift to the classroom with Ann M. Reagan's article entitled *Online Introductory Physics Labs: Status and Methods.* Finally, we continue on the topic of student education with *Perspectives from the field: Partnerships for Diversifying and Improving Ecology Education* by Teresa M. Mourad, Ecological Society of America.

I'd like to thank all of the participants and attendees at this year's CapSci 2012 and hope that you enjoy this small sampling of a great deal of work that was embodied in this weekend-long event.

Best,
Jacqueline Maffucci
Editor, The Journal of the Washington Academy of Sciences

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Anomaly Detection for Insulated Gate Bipolar Transistor (IGBT) under Power Cycling using Principal Component Analysis and K-Nearest Neighbor Algorithm

Edwin Sutrisno, Qingguo Fan, Diganta Das, and Michael Pecht

University of Maryland, College Park

Abstract

Insulated Gate Bipolar Transistor (IGBT) is a power electronic transistor used in medium to high power applications such as hybrid cars, railway traction motors, switch mode power supplies, and wind turbines. As more IGBTs find their application into larger and complex systems, the ability to detect and predict failures in IGBTs can provide a key advantage in driving down cost of maintenance and improving system availability and safety. This paper briefly discusses the common failure modes found in IGBTs under power cycling along with the experimental setup. Several electrical parameters are extracted and analyzed for fault using principal component analysis (PCA) and k-nearest neighbor (KNN) classification. The proposed algorithm is successfully shown to detect faults just before the IGBTs enter a final degradation stage toward failure.

Introduction

INSULATED GATE BIPOLAR TRANSISTOR (IGBT) is a power electronic device typically used in power inverters, traction drives, switching mode power supplies (SMPS), and other power switching/modulation applications. The key advantage of IGBT is its ability to combine the high switching speed of MOSFETs (metal oxide semiconductor field effect transistors) and the high current capability of BJTs (bipolar junction transistors) [1]. The latest push in power conservation and renewable energy has increased the demand in power electronic devices such as IGBTs, which warrants research into IGBT prognostics as a business potential [2, 3, 4].

The ability to detect anomaly and predict remaining useful life of systems is one of the key focuses of prognostics and health management (PHM) [5]. Information generated by a PHM system can support operators to schedule maintenance based on a system's health state and benefit from failure avoidance, maximized utilization of parts life, and improved availability and safety [6]. Cheng *et al.* [7] define prognostics and health management (PHM) as "an enabling discipline consisting of technologies and methods to assess the reliability of a product in its actual life cycle conditions to determine the advent of failure and mitigate system risk." In this paper we explore the ability of a PHM technique in detecting

anomalous degradation trends in IGBT by applying a k-nearest neighbor (KNN) algorithm. A previous work by Patil *et al.* [8] proposes an anomaly detection method for IGBT that analyzes data collected at a constant temperature. In this study we develop an algorithm with a capability of analyzing data with varying temperature.

Power Cycling Experiment and Data Collection

Power cycling is a self-induced thermal cycling due to variation in power dissipated by the device. In IGBT applications, power cycling is a dominant loading condition where stop-and-go profiles such as in electric vehicles cause the IGBT to heat up and cool down repeatedly throughout its life [9]. Mismatch of the coefficients of thermal expansion between different materials inside the IGBT package produces a fatigue stress that degrades metallization, die attach, and wire bonds [9, 10, 11]. These mechanical damages inside the IGBT packaging are followed by changes in the device's thermal and electrical characteristics that overtime push the loading condition above the device's safe operating area, leading to latchup or second breakdown. Figure 1 shows a cross-section schematic of the IGBT power module used in this study. Components and the corresponding materials are annotated.

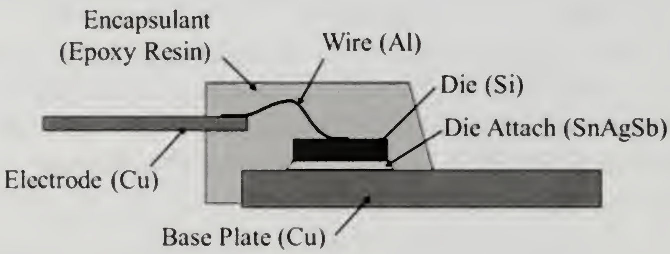

Figure 1. Schematics of an IGBT cross-section showing components and materials

Degradation in the die attach, for instance, reduces the effectiveness of the package in conducting heat from the die to the heat sink. This causes temperature in the die to become higher. Higher temperature increases the overall electrical resistance of the device which is reflected by an increase of the on-state collector voltage ($V_{CE(ON)}$). Figure 2 shows the trend of increasing $V_{CE(ON)}$ over time suggesting an increasing electrical resistance as the device degrades. In this figure, the device failed after 8300 cycles.

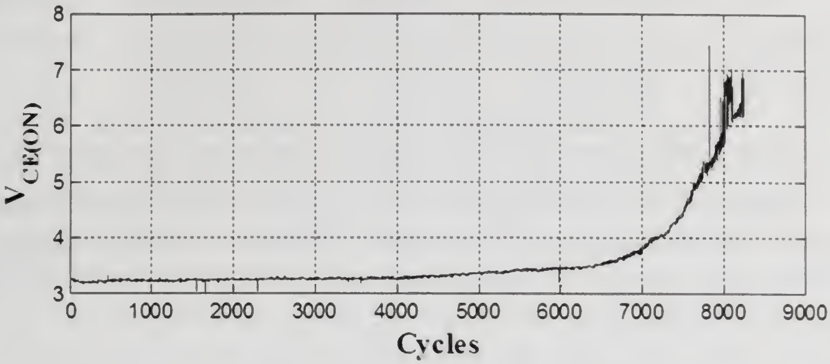

Figure 2. Plot of $V_{CE(ON)}$ of an IGBT under power cycling experiment. Horizontal axis shows the temperature cycles from the start of experiment until device failure. Loading condition is 1 kHz switching frequency, 50% duty cycle, and 50°C temperature swing. Plot shows data collected at 175°C.

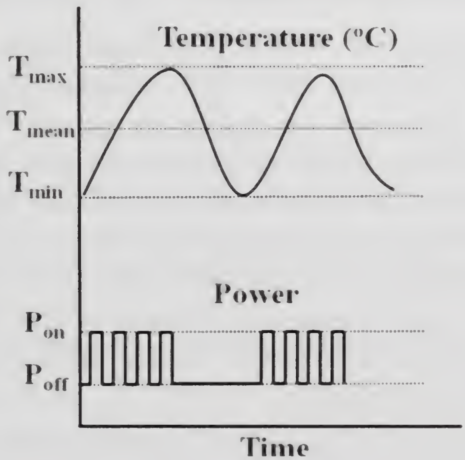

Figure 3. Illustration of a power cycling experiment. Top chart shows device temperature. Bottom chart shows power supplied into the device.

A power cycling experiment was performed on International Rectifier discrete IGBT modules built in with freewheeling parallel diodes [12]. Gate voltage was set at 15 V, which is sufficiently above the 5.5 V threshold voltage specified by the manufacturer. Gate voltage was applied as square waves with a switching frequency of 1 kHz. Temperature range in each cycle was set between minimum and maximum temperature limits, measured at the metal heat sink. The device was switched until temperature rose to T_{max} (maximum), then the power was cut off to let the device cool down to T_{min} (minimum) (see Figure 3 for illustration). Once the device temperature reached T_{min}, the square wave loading was repeated again and this cycle continued until device failure. Data were collected

every 1 second from the collector voltage, collector current, and heat sink temperature. No data were recorded when the device was in the cooling down mode.

Feature Extraction with Principal Component Analysis (PCA)

There are five parameters of the IGBT used toward building the algorithm features. The first one is the collector to emitter voltage when the gate is in the ON state during switching, $V_{CE(ON)}$, in volts. The second parameter is the collector to emitter voltage when the gate is the OFF state during switching, $V_{CE(OFF)}$, in volts. The third parameter is the collector to emitter current when the gate is in the ON state during switching, $I_{CE(ON)}$, in amps. The fourth parameter is the collector to emitter current when the gate is in the OFF state during switching, $I_{CE(OFF)}$, in amps. The last parameter is the heat sink temperature, T, in degree Celsius.

Seven samples of IGBT were put under the power cycling experiment. Data collected from five samples are used for algorithm training and the other two for algorithm testing. The training data are further categorized into healthy and faulty. Healthy data are defined as the first 120 observations collected in the experiment of the training samples where each observation consists of parameters $V_{CE(ON)}$, $V_{CE(OFF)}$, $I_{CE(ON)}$, $I_{CE(OFF)}$, and T as described previously. The total size of healthy data is 600 observations. Faulty data are defined as the last 300 observations before failure collected from each training sample. The total size of the faulty data is 1500 observations.

The next step is to perform principal component analysis (PCA) on the five parameters. PCA in this study is used to reduce redundancy in the data due to correlations among the parameters [13, 14]. From calculating the correlation matrix of the healthy data, we see that $V_{CE(ON)}$ is highly correlated with $I_{CE(ON)}$ with a Pearson correlation coefficient of -0.910, as shown on Table 1.

Table 1- Correlation matrix of IGBT parameters. Non zero off-diagonal entries suggest that the parameters are not independent.

	$V_{CE(ON)}$	$V_{CE(OFF)}$	$I_{CE(ON)}$	$I_{CE(OFF)}$	T
$V_{CE(ON)}$	1.000	0.219	-0.910	0.014	0.535
$V_{CE(OFF)}$	0.219	1.000	-0.230	0.042	0.020
$I_{CE(ON)}$	-0.910	-0.230	1.000	0.070	-0.510
$I_{CE(OFF)}$	0.014	0.042	0.070	1.000	0.065
T	0.535	0.020	-0.510	0.065	1.000

PCA works by transforming data points onto a new set of independent coordinates or principal components. Each principal component axis is oriented in the direction that captures the largest variance in the data in a descending order. This means the first principal component contains the largest variance, followed by the second principal component, and so on. PCA produces the same number of principal components as the number of input variables; however, we do not need to use all of the principal components because the last few principal components retain very little variance in the data and so do not provide much information for analysis. In this study we are using the first four principal components which account for 98% of the variance in the training data. PCA is performed on the normalized parameters, which are obtained by Equation 1.

$$X_{NOR\_i} = \frac{X_i - E(X)}{\sigma_X} \qquad \text{Equation 1}$$

where X_{NOR_i} is the normalized parameter for observation i, X_i is the measured parameter for observation i, $E(X)$ is the expected value for the parameter which in this study is the mean from the healthy data, and σ_X is the standard deviation of the parameter from the healthy data.

Anomaly Detection using KNN

k-nearest neighbor (KNN) is a technique in machine learning where a new data point is classified based on its proximity to other data points belonging to known classes, in this case healthy and faulty classes [15, 16]. Traditionally classification by KNN is done by a majority vote of the nearest neighboring points, where the class with the most number of neighbors wins the vote and classifies the new point as its own class.

In this study however, the KNN classification method is slightly modified by selecting three nearest neighbors from each class and then calculating the distance of the new point to the centroid of the neighbors of each class. An illustration of this distance-based KNN algorithm is shown on Figure 4. The advantage of using a distance based KNN instead of a majority vote based is that we obtain information on the trajectory of degradation in the feature space as we track the change in the distance.

The criterion for anomaly used in this study is when the distance of a point to the faulty class is closer than the distance to the healthy class

which suggests that the IGBT is now behaving more alike to a faulty device. This criterion can be summarized by the following statement:

Anomaly exists if: (Distance to Healthy Centroid– Distance to Faulty Centroid) > 0

Figures 5 and 6 show the result of the KNN anomaly detection algorithm applied on two IGBT samples. The two figures show that the algorithm successfully detects anomaly before failure when the distance curve crosses above the zero line.

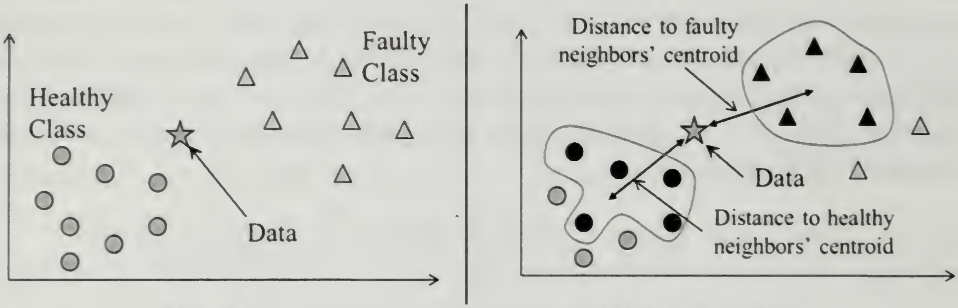

Figure 4. Illustration of a distance based KNN algorithm.

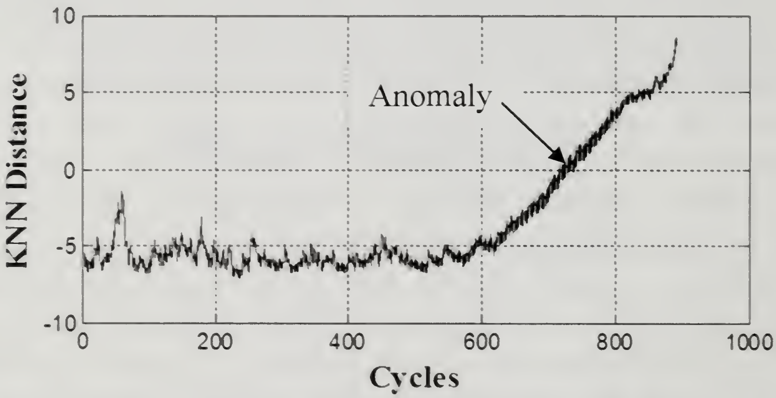

Figure 5. Anomaly detection for IGBT test sample #1. Anomaly detected at 717 cycles. The sample failed at 891 cycles. Experiment loading condition: 1 kHz switching frequency, 50% duty cycle, 100°C temperature swing.

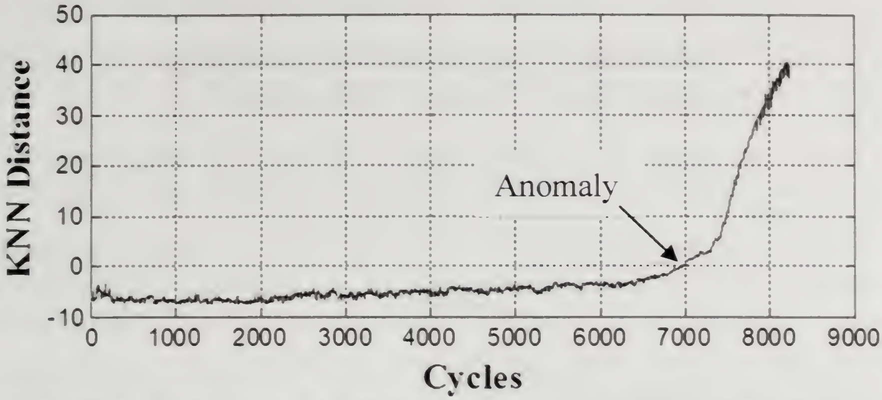

Figure 6. Anomaly detection for IGBT test sample #2. Anomaly detected at 6973 cycles. The sample failed at 8249 cycles. Experiment loading condition: 1 kHz switching frequency, 50% duty cycle, 50°C temperature swing.

Conclusions and Further Work

A method to detect anomaly in IGBT under power cycling has been proposed and shown to perform effectively on the experimental samples. The experiment loading condition was designed after the power cycling condition faced by IGBTs in field operations. We acknowledge that results here are based on limited number of samples and that there is an uncertainty involved when extending this method to real field conditions where the temperature cycles are not as uniform and controlled as the lab setup; however, this study suggests a feasible approach to devising an online anomaly detection system for IGBTs. Output from such system will provide valuable information for operators in determining support actions.

Further work of this study will include analyzing more samples, varying the loading conditions and improving the robustness of the algorithm in handling possible multiple fault classes as a result of multiple loading conditions. We will also explore the possibility of predicting the remaining useful life post anomaly detection.

References

[1] N. Patil, J. Celaya, D. Das, K. Goebel, and M. Pecht, "Precursor Parameter Identification for Insulated Gate Bipolar Transistor Prognostics," IEEE Transactions on Reliability, Vol. 58, No. 2, pp. 271-276, June 2009.

[2] P. Clarke, "Power Transistor Market to Grow 9% in 2011," EE Times, News & Analysis, June 24, 2011.

[3] A. Liu, "China's IGBT Market Set to Double by 2014," IHS ISuppli, Market Watch, Feb. 3, 2011.
[4] B. K. Bose, "Power Electronics and Motor Drives Recent Progress and Perspective," IEEE Transactions on Industrial Electronics, Vol. 56, No. 2, pp. 581-588, February 2009.
[5] B. Saha, J. R. Celaya, K. F. Goebel, and P. F. Wysocki, "Towards Prognostics for Electronic Components," 2009 IEEE Aerospace Conference, pp. 1-7, Big Sky, MT, March, 2009.
[6] C. Chen, G. Vachtsevanos, and M. E. Orchard, "Machine Remaining Useful Life Prediction Based on Adaptive Neuro-Fuzzy and High-Order Particle Filtering," Annual Conference of the Prognostics and Health Management Society, October 17, 2010.
[7] S. Cheng, K. Tom, L. Thomas, and M. Pecht, "A Wireless Sensor System for Prognostics and Health Management," IEEE Sensors Journal, Vol. 10, No. 4, April 2010.
[8] N. Patil, D. Das, and M. Pecht, "Mahalanobis Distance Approach for Insulated Gate Bipolar Transistor (IGBT) Diagnostics," Proceedings of the 17th International Conference on Concurrent Engineering, Cracow, pp. 583-591, September, 2010.
[9] M. Held, P. Jacob, G. Nicoletti, P. Scacco, M. H. Poech, "Fast Power Cycling Test for IGBT Modules in Traction Application," Proceedings of 1997 International Conference on Power Electronics and Drive Systems, Vol. 1, pp. 425-430, 1997.
[10] M. Ciappa, "Selected Failure Mechanisms of Modern Power Modules," Microelectronics Reliability, Vol. 42, pp. 653-667, 2002.
[11] M. Bouarroudj, Z. Khatir, J. Ousten, F. Badel, L. Dupont, and S. Lefebvre, "Degradation Behavior of 600 V–200 A IGBT Modules under Power Cycling and High Temperature Environment Conditions," Microelectronics Reliability, Vol. 47, pp. 1719–1724, 2007.
[12] International Rectifier, Data Sheet PD-97269A, "IRGB4045DPbF Insulated Gate Bipolar Transistor With Ultrafast Soft Recovery Diode," January 28, 2010. http://www.irf.com/product-info/datasheets/data/irgb4045dpbf.pdf
[13] K. Pearson, "On lines and planes of closest fit to systems of points in space," Philosophical Magazine, Vol. 2, pp. 559-572, 1901.
[14] S. Chatterjee and A. S. Hadi, "Regression Analysis by Example," 4th ed., John Wiley & Sons, Inc., Hoboken, New Jersey, 2006.
[15] E. Fix and J. L. Hodges Jr., "Discriminatory Analysis-Nonparametric Discrimination: Consistency Properties," Report Number 4, Project Number 21-49-004, USAF School of Aviation Medicine, Randolph Field, Texas, February, 1951.
[16] D. Hand, H. Mannila, and P. Smith, *Principles of Data Mining*, The MIT Press, Cambridge, MA, 2001.

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Simulation-based Military Training: An Engineering Approach to Better Addressing Competing Environmental, Fiscal, and Security Concerns

Jason E. Summers

Applied Research in Acoustics LLC

Abstract

Governments and militaries have long recognized that armed forces must engage in training in order to develop and maintain the proficiency necessary to effectually carry out those legitimate duties with which they are entrusted by their nations. This is made particularly salient by the increasing demands placed on individual members of the Armed Forces because of reduced staffing and increased task complexity. Yet training comes at a significant financial cost: roughly one third of the total defense budget in fiscal year 2012 is devoted to training. Moreover, military operations directly impact the environments in which they are carried out, while also burning significant quantities of fossil fuels. Broad societal, government-wide, and Department of Defense commitments to improved environmental management together with fiscal austerity measures enacted in response to the financial crisis will increasingly bound the scope of training operations, potentially limiting their utility. Often the challenges these bounds bring are approached only as a zero-sum problem of balancing interests, as exemplified by the 2008 Supreme Court trial over sonar training by the U.S. Navy. However, scientific advances have improved the understanding of physical phenomena and, together with innovations in modeling techniques and advances in computational power, this has enabled simulation-based training to augment live-action training for many military applications. In this paper, sonar training serves as an example through which to illustrate in broad overview the scientific and technological advances that have enabled enhanced capabilities for simulation-based training. It also provides a framework through which to examine how these technologies should be best developed to address the unique demands imposed by environmental, fiscal, and security concerns. Beyond enhanced knowledge of the ocean environment, improved models of sound propagation and scattering within that environment, and new algorithms for real-time computation, effective simulation-based training also requires an understanding of how the learning process is mediated by the fidelity of the simulation. This, in turn, impacts the efficacy of simulation-based training and the cost of developing a training system. Such considerations are a necessary part of any system-engineering process if it is to ensure that a training technology satisfies the diverse demands imposed on it.

Introduction

THE ARMED FORCES are the institutional embodiment of the responsibility legitimate governments have to protect their political communities from foreign acts of aggression that endanger life and property. Right exercise of this responsibility requires that governments ensure that armed forces are capable of effectually responding to aggression and that their response will conform to the laws of war. Both requirements are realized through military training. Readiness requires that militaries develop and maintain equipment and personnel capable of rapid and efficacious response to threats. Proficiency requires that militaries develop and maintain within their personnel skills necessary for combat. Long-term trends toward increasing task complexity and reduced staffing complicate fulfilling these demands, by placing greater demands on training to convey larger amounts of complex information in shorter periods of time.

Thus, training is a necessary and essential component of maintaining a standing military. But it is not without significant cost and consequence. The time, materials, and infrastructure necessary to conduct training all have substantial economic costs, as do wear and tear to military systems that result from training. In fiscal year 2012, roughly one third of the total defense budget is devoted to training – a figure that only partially reflects the full financial costs [1].

Training operations also can have both immediate and long-range environmental effects. Direct environmental disturbances that result in immediate effects include acoustic and thermal emissions together with impact on air and water quality from byproducts of combustion. Over a longer timescale, use of munitions in test ranges presents possible risks for soil, water, and groundwater contamination from unrecovered munitions and a direct risk to human and animal life from unexploded ordnance. At still longer timescales, military training operations impact climate change through use of fossil fuels.

Moreover, members of the Armed Forces participating in training operations – particularly live-fire exercises – face significant physical risks including loss of life [2]. Just as it is imperative for the military to minimize total casualties during active operations, so is it imperative for them to do so during the preparation for such operations.

Because there are compelling reasons for both conducting and limiting training, the situation seems to present a problem of balancing two competing obligations: an obligation to conduct training sufficient in

scope to maintain the readiness and proficiency of a standing military, and an obligation to limit training in order to better steward fiscal, environmental, and human resources. Arriving at a compromise between these obligations may be possible [3], though there is substantial disagreement over the proper balance [4, 5].

The present approach to resolving the competing obligations, particularly as it has been decided within the U.S. courts, relies on assessing the "balance of interests" between two parties within government or between government and another party. This reasoning, which decides based upon which party has a more compelling interest, is exemplified by the 2008 Supreme Court decision on the case between defendant Secretary of the Navy Donald C. Winter and plaintiff Natural Resources Defense Council, Inc. (NRDC). Writing for the majority, Chief Justice Roberts summarized in the opinion the court's assessment of the balance of interests:[6]

> We do not discount the importance of the plaintiff's ecological, scientific, and recreational interests in marine mammals. Those interests, however, are plainly outweighed by the Navy's need to conduct realistic training exercises to ensure that it is able to neutralize the threat posed by enemy submarines.
>
> Military interests do not always trump other considerations... In this case, however, the proper determination of where the public interest lies does not strike us as a close question.

While the opinion in this case rejected a limit on military training, two prevailing trends suggest that the frequency and scope of training will decrease in the future. The first is a series of fiscal austerity measures enacted in response to the financial crisis, which will likely extend across all elements of the Department of Defense (DoD). The second is a broad growth in societal commitments to improved environmental management that are increasingly finding regulatory embodiment in laws and policies. The risk posed by limiting training operations is that smaller scale operations may trade utility for other gains so that, ultimately, they are less cost effective.

Simulation-Based Training

Simulation-based training provides a technological alternative that resolves the tension between obligations by effectively mitigating the competition between their demands. Rather than conducting training in the conventional manner, simulation-based training uses computer-generated virtual environments to augment or replace portions of the real environment. By doing so, it can often reduce or limit risks to the participants and the environment while reducing overall costs. Provided that, in so doing, it can also ensure proficiency and readiness are achieved, simulation-based training can better jointly meet the broad scope of obligations faced by training operations.

There is a long history of use of simulation technology for training operations [7]. Today simulation technology employed by the military spans a broad range including desktop flight trainers derived from commercial products, immersive virtual-reality training environments, and complex tactical team trainers comprising multiple sites each replicating the physical environment of one or more military platforms.

The recently developed primer on modeling and simulation from the National Training and Simulation Association defines modeling as "the representation of an object or phenomena," which "may be mathematical, physical, or logical representations of a system, entity, phenomenon, or process" [7]. Simulation, in turn, is defined as "a representation of the functioning of a system or process," comprising the collective functioning of one or more interconnected models that together predict the time evolution of a system [7].

Systems for simulation-based training, as depicted schematically in Figure 1, comprise simulation, with various constituent models; environmental and other databases, which serve as input for models; and rendering algorithms, which enable presentation of simulated data to users.

As depicted in Figure 2, simulation-based training exists on a continuum, ranging from augmentation of the real environment with simulated, virtual entities to fully simulated, purely virtual environments.

Likewise, rendering takes various forms depending on the mode by which those being trained interact with the output of the simulation. These include (1) first-person presentation, as in immersive virtual reality; (2) third-person screen-based presentation, as in video games; and (3) technology-mediated presentation, as in radar or sonar training for which

simulation output replaces real-world input to standard technological interfaces.

In the first case, simulation output is rendered to sensory transducers (such as display goggles and headphones). In the second case, simulation output is similarly rendered to sensory transducers (such as display screens), but from a third-person perspective. In the third case, simulation output is rendered as the output of data from one or more sensors that are modeled within the virtual environment.

The distinction between the first and second modes of rendering is quite fluid, as demonstrated by video games that adopt a first-person perspective. Such a distinction relies upon assumptions about the ontological status that trainees assign to simulation. However, the ontological status afforded to simulation – the subjective sense of whether something is "like real life" – cannot be described meaningfully in such simple terms. An alternate approach, discussed later in this paper, grounds this subjective assessment in biology, giving an objective basis for understanding the full spectrum over which simulation can be perceived "as real."

Nonetheless, the type of rendering constrains the type of simulation and the constituent models it uses. Rendering bounds the physical and temporal scale and limits over which simulation is carried out. Likewise, distinct display modalities make distinct demands on the physics that a simulation must incorporate. This is particularly well illustrated by the case of simulation-based sonar training.

Simulation-Based Sonar Training

In recent years concern over the risk posed by quiet submarines operating in littoral waters has motivated the Navy to increase their use of active sonar to detect these threats [8]. Though computational algorithms assist human operators, detection and classification of submarines using active sonar is an "incredibly complex" task that requires substantial amounts of training in realistic environments for operators to achieve proficiency [9]. However, some evidence suggests that active sonar may adversely affect marine mammals, in particular, certain species of whale [10-13].

The Navy has used simulation-based sonar training in various forms for more than fifty years [14-15], largely due to the pedagogical, logistic, and cost advantages it offers. Peter W. Singer reports that "the Navy estimates that its use of gaming at bases, in lieu of doing the same

exercises at sea, saves it some 4,000 barrels of fuel a year" [16]. Therefore, despite legal decisions that allow for ongoing live training, the Navy has supported development of new simulation-based training. This has included support for the Surface ASW Synthetic Training (SAST) program, which developed simulation-based training for the SQQ-89A(V)15 sonar system that was the subject of Winter v. NRDC [17].

Sonar provides operators with a technologically mediated connection to the physical world; a trait it shares with other military sensing technologies such as radar. More than simply enhancing existing sensory modalities of operators, these technologies categorically extend the human capacity for sensing by enabling distinct new ways of observing the world but displaying the sensing data to operators so they can be perceived.

Of particular interest here is active sonar, in which a sonar transducer emits acoustic signals and uses the returns scattered back from the environment to detect, classify, and localize targets of interest.

Active-sonar systems typically present information to operators through visual displays, auditory displays, and the output of automation algorithms. Each display effectively selects and highlights particular aspects of the data and the underlying physical processes by which it was generated. For example, a conventional A-scan display (a plot of amplitude versus time) for the time series associated with a particular spatial beam provides little or no useful information about the Doppler shifts associated with each return. Neither does a GEOSIT display in which B-scan displays (displays of amplitude mapped to intensity plotted as a function of time) are mapped to range and bearing. However, the equivalent spatial auditory display [18] conveys some Doppler information and a specialized spectral display might convey even more.

Because sonar mediates the connection of operators to the physical world, simulation for sonar can take two distinct approaches. In the first, simulation models the phenomena of the displays themselves and renders the simulation results directly to the displays. Alternately, in the second, simulation models the phenomena of the physical environment and renders the simulation results in the form of virtual sensor output. This virtual data then replaces the data generated by the real world.

The latter approach, termed simulated stimulation (sim-stim), is more computationally demanding and requires greater knowledge of the

physics of the environment. However, simulation at the environment level offers significant advantages over simulation at the display level.

Display-level simulation is tied to the particular display and sensor system for which it is developed, making upgrading or repurposing of simulation components potentially costly and time consuming. Moreover, it relies (at least implicitly) on a form of reduced-dimension latent-variables model, which is inherently susceptible to errors if the display data used to develop the models are not truly representative.

A number of recent advancements have enabled broader application of sim-stim simulation-based sonar training. First, advances in computational power via multicore CPU and many-core GPU processors, together with algorithms able to utilize these new architectures to their best advantages, allow real-time computation for scales of problem that were previously intractable. Many numerical techniques in underwater acoustics are amenable to parallelization (see, *e.g.*, [19]), though work is ongoing. Second, there have been significant advances in understanding the physics of underwater acoustics in shallow water. Development of modern high-resolution broadband sonar systems had, until recently, outpaced growth in knowledge of fundamental physical mechanisms of sound propagation and scattering in the ocean, particularly in shallow-water regions for which boundary interactions are significant.

Efforts over the last fifteen years have specifically sought to improve the knowledge of the physical processes underlying scattering from the air/water [20] and water/sediment interfaces [21], which has recently led to development of new computational models.

Similarly, fundamental research efforts have been directed toward the physical mechanisms responsible for spurious target-like echoes (termed "clutter") [22]. This has recently resulted in new models for scattering from target-like objects in the environment [23] and new models that explain how scattering from boundaries can lead to target-like clutter [24].

While new developments make simulation-based training for active sonar more viable and realistic, it remains necessary to determine how to best utilize new models within a simulation system. Likewise, the level to which simulation is carried out must be determined. Ultimately, all simulation relies on a set of assumed phenomenological models and archival databases to serve as inputs to physics-based models. Simulation-based sonar training must, for example, determine whether the physical

properties of the ocean environment will be based on archival databases and heuristic models or computed by coupled ocean/acoustic models [25].

In order to assess the answers to such questions, it is necessary to consider the relationship of simulation fidelity to training efficacy.

Simulation Fidelity and Training Efficacy

Simulation-based training must, when properly employed, result in the desired results of proficiency and readiness. If not, untrained or improperly trained combatants may hinder, impede, or prevent the Armed Forces from performing its functions. Failures of efficacy for training technologies belong to one of three types. First is *omission*, which occurs when knowledge and skills are not taught or fail to transfer from the training environment to the real world. Second is *negative transfer*, which occurs when exposure to training technology results in slowed learning in the real world. Third is *negative training*, which occurs when training results in acquisition of incorrect knowledge, skills, or behaviors. Avoiding these failures requires careful consideration of fidelity and how it is allocated.

In the field of modeling and simulation, *fidelity* describes "the degree to which the representation within a simulation is similar to a real-world object, feature, or condition in a measurable or perceived manner" [26]. Thus, while fidelity is intrinsically measurable, there is no single scale on which it is measured and no convenient means of comparing fidelity. Typically fidelity is expressed in terms that suggest some topological knowledge about relationships (higher or lower, nearer or farther) without knowledge of a metric.

Beyond modeling the physical environment with an appropriate degree of veracity, fidelity requires representation of appropriate complexity in scene, scenario, and tasks. It also requires that joint behaviors such as relations between stimuli and the response environment be represented with an appropriate degree of faithfulness to reality [26-27].

In many cases, efficacy of simulation-based training is governed by the fidelity of the virtual environment. Simulation fidelity is generally thought to enhance the transfer of training from virtual environments to the real world. Moreover, failure to replicate real-life scenarios with sufficient fidelity can produce absent, false, or distorted cues, the consequences of which can be negative transfer and negative training.

For this reason, allocation of fidelity within a simulation is critical. The fidelity with which task-related information, such as perceptual cues, is presented has a direct bearing on the efficacy of the training experience.

The fidelity with which distractors and other elements of the environment that complicate task performance are presented is likewise critical.

However, in other cases, fidelity requirements can often be relaxed. In doing so, suppressing artifacts associated with lower fidelity – and thereby avoiding creation of false or distorted cues – is generally more important than reproducing phenomena that are not task related.

Yet, it is also necessary to reject the "naïve but persistent theory" that fidelity alone is sufficient to ensure efficacious training [28]. Simulation alone is not training, but serves the purposes of a broader training program [29]. Therefore failures of omission can result from the training design in which simulation is employed. To avoid omission it is also necessary that simulation fidelity be matched to the training design. This is not trivial because the critical relationships between user, task, and environment may not be known a priori. Moreover, theories of attention and working memory suggest that providing excess fidelity not directly tied to training goals may be harmful [29-32].

Even if relationships between user, task, and environment are replicated, ontological distinctions cause stress, motivation, and consequences to differ between real and simulated environments. The result of this is reduced transfer of training [29, 33]. Efficacy of training depends on the relationships between affective, cognitive, and physical states in the real and simulated environments [34]. For example, to effectively train for performance in stressful environments, task learning and stress exposure must be integrated [35].

These same issues animate consideration of negative transfer and negative training. Designers of simulation-based training must respect the complexity inherent in the process of acquiring new knowledge and skills. In so doing, they will be required to consider the relationships between user, task, and environment, rather than unilaterally "solve" issues through an undifferentiated technological approach.

Unfortunately, in practice, development of simulation-based training often fails to adhere to these principles. Equating high levels of physical fidelity with training efficacy has a long history and remains commonplace [30].

Presence

The belief that improvement of simulation fidelity necessarily will result in enhancement of transfer of skills and learning from a virtual environment to the real world is generally grounded in the notion that fidelity enhances the "sense of being there" – termed "presence" – and that learning that occurs in virtual environments that are experienced "as though it is real" is more likely to have real-world impact.

Presence, being a subjective measure typically evaluated through questionnaires, is rather imprecise and of limited use in developing a simulation-based training system. Thus more recent work has sought to ground the concept in biology.

Functionally, a simulation can be said to have achieved presence if users respond to the synthetically generated proximal cues of the virtual environment as though they correspond to distal stimuli in the real world. This phenomenon, which has also been termed "place illusion" [36], results from virtual environments that are veridical in terms of their congruence with the empirically derived and ecologically adapted cognitive models and methods used for interpreting reality. That is, they reproduce with appropriate fidelity the complex relationships between user, task, and environment.

Mel Slater has described an analogous "plausibility illusion" which he defines as the experience "that the scenario being depicted is actually occurring," which "is determined by the extent to which the system can produce events that directly relate to the participant, the overall credibility of the scenario being depicted in comparison with expectations" [36]. Provided that both illusions are present, Slater argues that "participants will respond realistically."

A related but distinct theoretical framework has been developed by Slater *et al.* [37]. In this framework presence and plausibility, illusions are a response to stimuli that satisfy three requirements: (1) a low-latency sensorimotor loop between sensory data and proprioception (*i.e.*, the internal perception of one's own volitional motion), (2) statistical plausibility of sensory data in relation to the empirical probability distribution over environments in the real world, and (3) appropriate correlations between egocentric behaviors and the response of the environment, on both local and global scales. While Slater focused on virtual-reality systems in which humans interact directly with the virtual environment, much simulation-based training is for systems in which

connection to the physical world is technologically mediated. Because this interface is unchanged between virtual training and the real world, the notion of presence that is constrained by the "sensorimotor contingencies afforded by the virtual reality system," is problematical or irrelevant. The primary question is whether the simulation can sustain the plausibility illusion, "the illusion that what is apparently happening is really happening (even though you know for sure that it is not)." Requirements (2) and (3) are related to the plausibility illusion largely through reaction of the virtual world and entities in it to egocentric actions, *i.e.,* "correlations between external events not directly caused by the participant and his/her own sensations (both exteroceptive and interoceptive)." Examples include both shadows and echoes that behave in response to the actions of the participant.

The requirements, and particularly the last two, are naturally interpreted within the framework of ecological psychology in general and Brunswig's probabilistic functionalism in particular [38]. From this perspective, presence requires the virtual environment to correspond to empirically derived probabilistic notions about real-world ecology. Requirement (2) reflects the expectation that stimuli will conform to empirical estimates of the probability distributions describing ecological models of the real world. This requirement extends across temporal and spatial scales, including not only naïve physics and cause-and-effect relationships, but also expectations about the narrative structure of scenes [39].

Though it has not been shown, it is likely that this reasoning applies not just to the response of the environment to egocentric behaviors, but also to the naïve physics of task/goal oriented behaviors by other entities or elements in the environment. For example, if the task were to be pursuing an individual in a complex environment, accurately simulating the acoustic response of the environment to the footsteps of the individual being pursued would be important for ensuring users respond to the simulation as though real in the same manner that simulating egocentric responses of the environment have been shown to be in other cases. Task-relatedness, rather than, or together with egocentricity, is likely to be what determines the importance of fidelity [40].

While the functional definition of presence does alter the meaning of the term in some sense, it also removes one of the major failings in application of the term. The conventional view holds that presence, in the sense that a virtual environment is "interpreted as being real" is necessary

for transfer of training to the real world [41]. But the universality of this requirement has been generally refuted by a growing body of recent work following the seminal findings of Green *et al.* [42]. This work has shown that perceptual and cognitive skills gained by playing conventional action video games transfers and generalizes to real-world tasks. Yet, these games do not produce a sense of presence in the conventional sense.

This difficulty is largely resolved by the functional definition of presence. While conventional video games typically do not produce a sense of "being there," they do produce neurological and physiological responses that are the same as responses to the real world with respect to those aspects that transfer. For example, Green *et al.* [42] found that training from first-person shooter games enabled players to make decisions more rapidly and accurately in real-world scenarios – a cognitive process for which playing such games evokes the same neurological and physiological processes as real-world experiences.

Likewise, this functional understanding of presence and its effect on transfer of learning accounts for prior findings that simulations that provide a sense of "being there" are required for the acquisition of complex behaviors in virtual environments and the transfer of these experiences to the real world [41, 43], while allowing that simulations that are not immersive, but produce identification with avatars can result in changes in behavior [44].

Presence (as functionally defined) ensures that a virtual training environment is actually training users for a real-world task by ensuring that the simulation engages users in the same physiological and neurological processes they are being trained to perform in the real world. Thus, it is simply a restatement of the anecdotal finding that simulation-based training should ensure appropriate fidelity in representation of task-critical elements of the virtual environment.

Within this framework, the purpose of allocating fidelity to task-related aspects of the simulation is understood as ensuring that the same neurological and physiological processes are used. In the same way, allocating fidelity to components of the environment that complicate the task ensures that the training experience replicates all aspects of cognitive function including load and attentional effects that result from distractors.

Simulation-Based Sonar Training

Determining the level and allocation of fidelity needed for simulation-based sim-stim sonar training requires understanding the display phenomena operators make use of during task performance and how these phenomena map to physical processes. Figure 3 is an example of a taxonomy of phenomena for one particular mode of display, illustrating one particular branch. Additionally, it is necessary to understand the mapping from phenomena observed by operators to models of physical phenomena, as shown schematically in Figure 4. Such taxonomies and mappings provide a basis for selecting the constituent models of a simulation.

Significantly, the understanding of the relationship between fidelity and training efficacy presented previously suggests that not only is the fidelity of simulated target entities important, but also the fidelity of clutter, noise, and reverberation that distract from, or otherwise complicate, the task of sonar operators.

The cognitive processes involved in detection and classification cannot be reduced to pattern recognition alone. They also involve discriminating between similar distractors and are modified by the complexity of the task the environment presents. Likewise, simulation of clutter, noise, and reverberation is important to ensure proper training on the use of automation; such signals can trigger false alarms, which further complicate the task of operators.

Discussion: Cost-Effective Design for Simulation-Based Training Systems

Taken collectively, the new possibilities offered by simulation-based training can enable governments and militaries to provide necessary training for their armed forces able to develop and maintain the proficiency at or above current levels while, at the same time, more fully addressing fiscal, environmental, and safety concerns.

Virtuality also introduces unique benefits. Training can be conducted more frequently because of the enhanced availability virtual technologies allow. Training can also be more flexible, incorporating elements that would be difficult or impossible in live training. For example, virtual training can depict potential threats that cannot be present during live training. Both of these benefits have pedagogical advantages.

However, such gains are neither automatic nor guaranteed. Simulation-based training systems able to fulfill the promise of the technology must be developed in such a way that fidelity is allocated to best achieve efficacy while accounting for inherent limitations and concerns of cost.

Moreover, the tacit assumption that simulation-based training is cost effective is not always accurate. Initial development costs for such systems are high; the technology ages rapidly, which increases the effective lifetime costs; and other alternatives may provide similar performance with lower initial and lifetime costs. Thus, it is only in those situations where the risks associated with live training are high that cost effectiveness is reasonably assured [29].

This relationship can be depicted graphically, as shown in Figure 5. Prudential ethical decisions bound the allowable risk and cost of live-action training in the real world. Training scenarios that exceed these limits on risk and cost must be conducted virtually, if at all. Scenarios within these limits can be conducted as live-action training, but the range of particular combinations of cost and risk for which live training is appropriate are constrained to fall within the area under a curve that is determined by the lifetime cost of effectual simulation-based training. This dependence on costs leads to a family of curves. As new technologies enable effectual training at lower cost, the effective cost limit associated with live-action training is reduced, the risk threshold remains fixed, and the total area under the curve decreases. In practice, the curves associated with effectual simulation-based training are specific to particular training environments and, in some cases, cannot be drawn because simulation-based training is not yet effectual.

Transfer of learning from simulation-based training to the real world cannot be assured through "brute engineering force" that attempts to achieve very high levels of fidelity [29]. Generally, if task and training environment are identical, perfect transfer is expected. This explains the drive for physical fidelity in virtual environments, particularly for technologically mediated weapons systems such as radar, sonar, and unmanned vehicles in which the interface remains consistent between training and real life. But stewardship concerns must balance the goal of ensuring efficacy by achieving high levels of fidelity.

Acknowledgements

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References

[1] The FY12 budget allocated $172 billion of Operation and Maintenance funds to support training and readiness out of a $553 billion base budget, http://www.whitehouse.gov/omb/factsheet_department_defense (Last retrieved 15 March 2012).

[2] Mortality rates among recruits in basic training are lower than those for the civilian population, as reported by Stephanie L. Scoville, "Mortality During U. S. Armed Forces Basic Training: A 25-Year Review (1977-2001)" (PhD diss., Uniformed Services University of the Health Sciences, 2002). However, accidents consistently rank as one of the leading causes of death among active-duty military, even during wartime, as reported in "Military Casualty Information," DoD Statistical Information Analysis Division, accessed September 24, 2011, http://siadapp.dmdc.osd.mil/personnel/CASUALTY/castop.htm

[3] Stephen Dycus, *National Defense and the Environment* (Hanover, NH; U. Press of New England, 1996).

[4] Stephen Dycus, "Osama's Submarine: National Security and Environmental Protection After 9/11," *William & Mary Environmental Law and Policy Review* 30, no. 1 (2005): 1-54. Retrieved from http://scholarship.law.wm.edu/wmelpr/vol30/iss1/2 (Last retrieved 24 September 2011).

[5] U. S. Government Accountability Office, *Military Training: Compliance with Environmental Laws Affects Some Training Activities, but DOD Has Not Made a Sound Business Case for Additional Environmental Exemptions*, GAO-08-407 (Washington, D.C.: March 7, 2008), http://www.gao.gov/new.items/d08407.pdf

[6] Winter v. NRDC, 555 U.S. 1-12 (1999), http://www.supremecourt.gov/opinions/08pdf/07-1239.pdf

[7] National Training and Simulation Association, "A Primer on Modeling and Simulation: The World of M&S," (2011). http://www.corporatepress.com/clientfiles/ntsa/files/primeronmodelingandsimulation.pdf (Last retrieved 15 March 2012).

[8] John R. Benedict, "The Unraveling and Revitalization of U. S. Navy Antisubmarine Warfare," Naval War College Review 58, no. 2 (Spring 2005): 111-12.

[9] W. H. Wulfeck and S. K. Wetzel-Smith, "Design of Instruction for Incredibly Complex Tasks," Presentation to the DOD Accelerated Learning Workshop, 22-23 July 2008.

[10] Eugene H. Buck and Kori Clavert, Congressional Research Service Reports, Active Military Sonar and Marine Mammals: Events and References, 1 January 2008.

[11] Douglas P. Nowacek, Lesley H. Thorne, David W. Johnston, and Peter L. Tyack, "Responses of cetaceans to anthropogenic noise," Mammal Review 37, no. 2 (2007): 81-115.

[12] Peter L. Tyack, Walter M. X. Zimmer, David Moretti, Brandon L. Southall, Diane E. Claridge, *et al.*, "Beaked Whales Respond to Simulated and Actual Navy Sonar," PLoS ONE 6, no. 3 (2011).

[13] Mariana L. Melcon, Amanda J. Cummins, Anne E. Simmonis, Simone Baumann-Pickering, Marie Roch, et al., "Assessing the effects of mid-frequency sonar on beaked whales in Southern California (A)," *Journal of the Acoustical Society of America* 129, no. 4 (2011): 2395.

[14] Robert R. Mackie and Albert Harabedian, "A Study of Simulation Requirements for Sonar Operator Trainers," Technical Report: NAVTRADEVCEN 1320-1, AD0603329, Human Factors Research, Los Angeles, California, March 1964.

[15] Herbert Berke, "A Technique for Shipboard Sonar Echo Simulation for Training," Technical Report: NAVTRAEQUIPCEN IH-231, AD-A027096, Naval Training Equipment Center, Orlando, Florida, June 1976.

[16] Peter W. Singer, "Meet the Sims ... and Shoot Them," Foreign Policy March/April 2010. Retrieved from http://www.foreignpolicy.com/articles/2010/02/22/meet_the_sims_and_shoot_them (Last retrieved 18 July 2010).

[17] "Surface ASW Community Teams with Submarine Force for Improved Training Capability," Team Submarine Public Affairs, NAVSEA Newswire, September 11, 2008.

[18] Jason E. Summers, "Information-theoretic performance analysis of azimuthal localization for spatial-auditory display of beamformed sonar data," Proceedings of ICAD 2010, the 16th International Conference on Auditory Display, Washington, D.C., 9-15 June 2010.

[19] See *e.g.* P. Hursky and M. B. Porter, "Accelerating underwater acoustic propagation modeling using general purpose graphic processing units," Proceedings of OCEANS 2011, Waikoloa, HI, 19-22 September 2011.

[20] Roger C. Gauss, Robert F. Gragg, Daniel Wurmser, Joseph M. Fialkowski, and Redwood W. Nero, "Broadband Models for Predicting Bistatic Bottom, Surface, and Volume Scattering Strengths," Technical Report, NRL/FR/7100—02-10,042, Naval Research Laboratory, Washington, D.C., 30 September 2002.

[21] Darrell R. Jackson and Michael D. Richardson, *High-Frequency Seafloor Acoustics* (Springer, New York, 2007).

[22] Proceedings of the International Symposium on Underwater Reverberation and Clutter, Peter L. Nielsen, Chris H. Harrison, and Jean-Claude Le Gac, Eds., Villa Marigola, Lerici, Italy, 9-12 September 2008.

[23] Charles W. Holland, Thomas C. Weber, and Giuseppe Etiope, "Acoustic scattering from mud volcanoes and carbonate mounds" *J. Acoust. Soc. Am.* 120, (2006): 3553-3565.

[24] D. A. Abraham and A. P. Lyons, "Novel physical interpretations of K-distributed reverberation," IEEE *J. Oceanic Engineering*, 27, (2002): 800- 813.

[25] Lermusiaux, P.F.J. *et al.* "Coupled Ocean–Acoustic Prediction of Transmission Loss in a Continental Shelfbreak Region: Predictive Skill, Uncertainty Quantification, and Dynamical Sensitivities." *IEEE J. Oceanic Engineering*, 35.4 (2010): 895-916

[26] DoD Directive 5000.59-M "Glossary of Modeling and Simulation Terms" (1998).
[27] C. E. Osgood, "The similarity paradox in human learning," *Psychological Review* 56 (1949): 132-43.
[28] H. Ellis, *The Transfer of Learning* (New York: Macmillan, 1965).
[29] J. K. Caird, "Persistent Issues in the Application of Virtual Environment Systems to Training," Annual Symposium on Human Interaction with Complex Systems (1996): 124-32.
[30] Euardo Salas, Janis A. Cannon-Bowers, and Clint C. Bowers, "Training in organizations: Myths misconceptions, and mistaken assumptions," *Research in Personnel and Human Resource Management* 17 (1999): 123-61.
[31] N. Dahlstrom, S. Dekker, R. van Winsen, and J. Nyce, "Fidelity and validity in simulator training," *Theoretical Issues in Ergonomics Science* 10, no.4 (July/August 2009): 305-14.
[32] Greggory Tibbits, Lesley Jolly, Lydia Kavanagh, and Liza O'Moore, "Educational Technologies and Learning Objectives," Proceedings of the 2010 AaaE Conference, Sydney, Australia (2010): 518-25.
[33] Christopher K. McClernon, Michael E. McCauley, Paul E. O'Connor, and Joel S. Warm, "Stress Training Improves Performance During a Stressful Flight," Human Factors: The Journal of the Human Factors and Ergonomics Society, 53, no.3 (June 2011): 207-18.
[34] D. A. Overton, "State-dependent learning produced by depressant and atropine-like drugs," Psychopharmacology 10 (1964): 6-31.
[35] N. Friedland and G. Keinan, "Training effective performance in stressful situations: Three approaches and implications for combat training," Military Psychology 4 (1992): 157-74.
[36] Mel Slater, "Place illusion and plausibility can lead to realistic behaviour in immersive virtual environments," Philosophical Transactions of the Royal Society B 364 (2009): 3549–57.
[37] Mel Slater, B. Lotto, M. M. Arnold, M. V. and Sanchez-Vives, "How we experience immersive virtual environments: the concept of presence and its measurement," Annuario de Psicologia 40, (2009):193-201.
[38] M. K. Dhami, R. Hertwig, and U. Hoffrage, "The Role of Representative Design in an Ecological Approach to Cognition," *Psychological Bulletin* 130 (2004) 959–988 .
[39] P. Chueng and P. Marsden, "Designing Auditory Spaces to Support a Sense of Place: The Role of Expectation," Position Paper for The Role of Place in On-line Communities Workshop, CSCW2002, New Orleans, November 2002.
[40] Personal Communication, Paul Bello, Office of Naval Research.
[41] D. M. Romano and P. Brna, "Presence and Reflection in Training: Support for Learning to Improve Quality Decision-Making Skills under Time Limitations," CyberPsychology & Behavior, 4 April (2001): 265-277. [Online].
[42] C. Shawn Green and Daphne Bavelier, "Action video game modifies visual selective attention," *Nature* 423, 29 May (2003): 534-537.
[43] J. G. Tichon, "Using Presence to Improve a Virtual Training Environment," CyberPsychology & Behavior", 10 April (2009): 781-788.
[44] J. Fox, and J. N. Bailenson, "Virtual self-modeling: The effects of vicarious reinforcement and identification on exercise behaviors," Media Psychology, 12, (2009): 1-25.

Figure 1. A high-level schematic of a notional simulation-based training system illustrating the general components and flow of information. While rendering only receives simulation data, the nature of the rendering determines the nature of the simulation (a concept that is depicted here by a dotted arrow). The responses of trainees both alter the rendering (*e.g.*, in response to head motion) and require changes in the simulation (*e.g.*, in response to a change in the signal being transmitted).

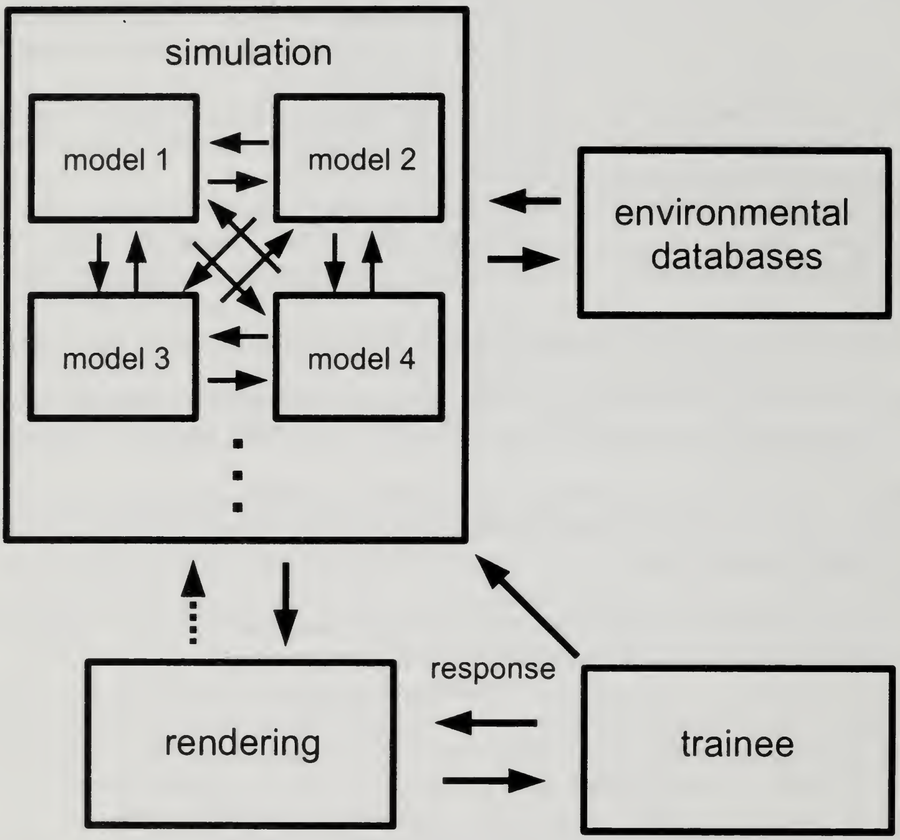


Figure 2. As depicted here, training exists on a continuum between live training, which occurs in the real environment, and virtual training, which occurs in the virtual environment. Between these poles, constructive training uses mixed reality to augment the real or virtual environment.

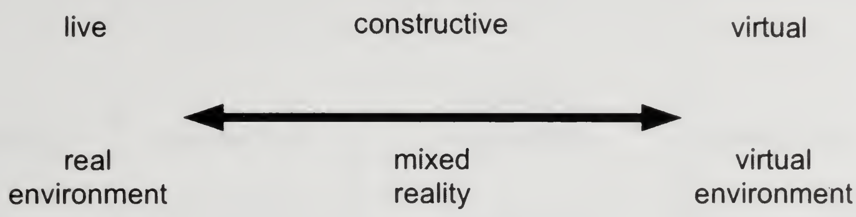


Figure 3. A graphical depiction of a taxonomy of phenomena for active sonar. One branch of the taxonomy is shown for clutter echoes that are discrete, and persistent, such as the echo from a scatterer on the seafloor or a large biological entity.

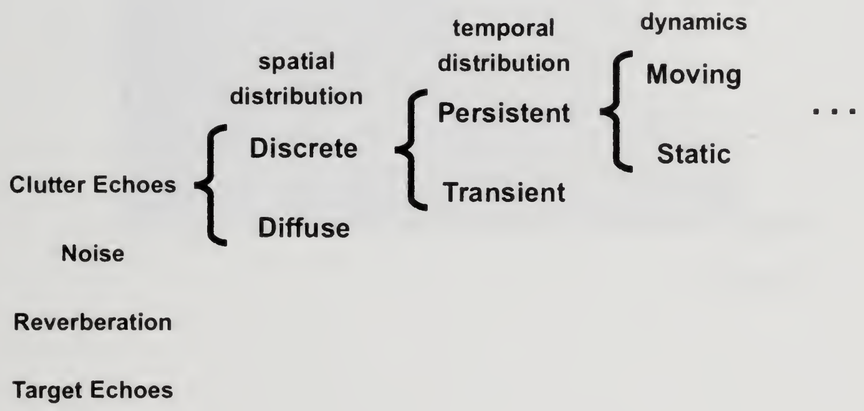


Figure 4. A schematic graphical depiction of the translation from phenomena observed by active-sonar operators, to physical phenomena, to physical mechanism, to mathematical and computational models. The circles show the item under consideration for each category.

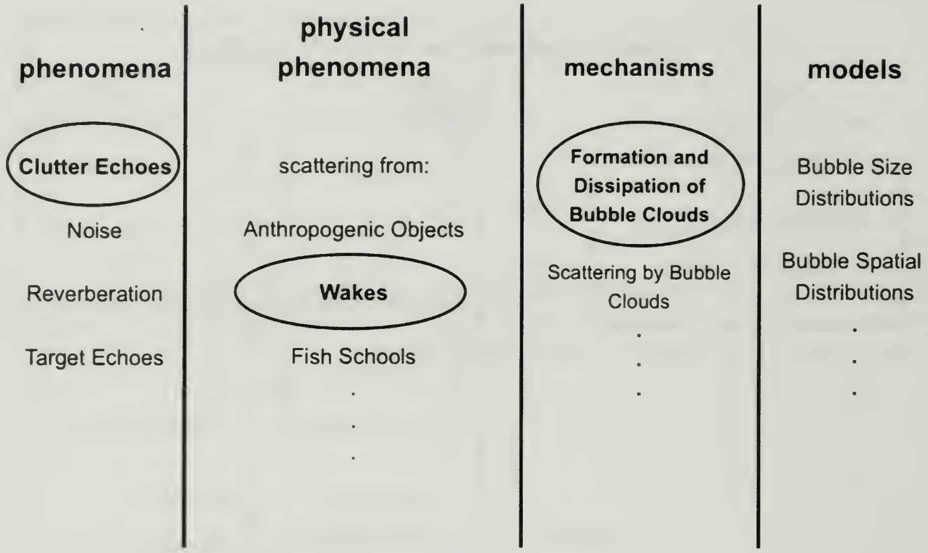
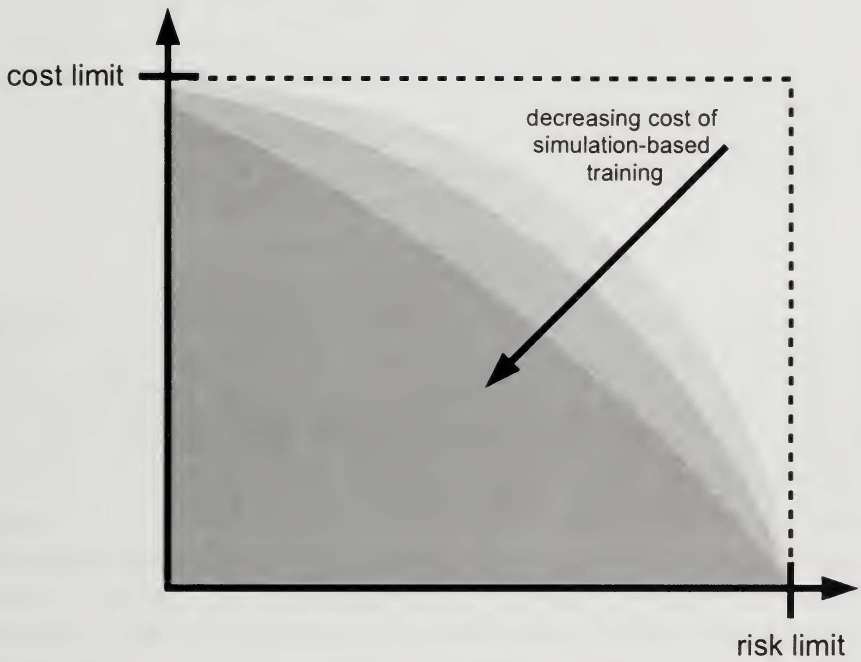


Figure 5. A notional depiction of the cost-risk constraints on the viability of live versus virtual training: only the area bounded by the cost and risk limits allows for live training; in the cross-hatched region training must be virtual, if it is possible at all. The three curves depict varying levels of cost effectiveness of simulation-based training, with the shaded areas under the curves representing the reduced region for which live training is appropriate.



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Online Introductory Physics Labs: Status and Methods

Ann M. Reagan

College of Southern Maryland, La Plata, MD

Abstract

Nearly 400 US colleges and universities offering undergraduate introductory physics courses were surveyed to determine the extent to which introductory physics instruction is currently available in a fully online format. A second survey, targeting those institutions offering online introductory physics courses, identified current approaches to and plans for making the corresponding physics laboratory course components available online. A single approach towards online laboratories was selected, and a set of experiments was developed based on program goals for technical rigor, student engagement, cost, and suitability for deployment in an online environment. Preliminary results and "lessons learned" from the deployment of these experiments in an online instructional format are discussed, as well as recommended next steps for the development of a research-based online physics laboratory curriculum.

Introduction

Opportunities for online education continue to expand. The most recent report of the Babson Survey Research Group shows online learning enrollment increasing at more than ten times the rate for post-secondary education overall, with 31% of all students in higher education now enrolled in at least one online course. [1] The availability of online opportunities is becoming pervasive, with nearly two-thirds of institutions offering face-to-face undergraduate-level courses now offering similar courses online. [2] This availability of online courses and programs, however, varies significantly by discipline. More than a third of all institutions offering full degree programs in business, computer/information science, or Liberal Arts/General Studies also offer full degree programs in the same disciplines completely online.[3] However, less than 10% of all US undergraduate institutions offering physics courses provide even one section of an introductory physics course in an online format.[4]

As online learning continues to make inroads into all disciplines, research-based methods will be needed to assure the quality of the online learning experience keeps pace with the quantity of online learning opportunities. A significant body of literature exists regarding the science of face-to-face undergraduate physics teaching and learning,[5] with gains in standardized tests and large sample sizes providing objective evaluation

criteria for competing instructional approaches.[6,7,8] Similar data are scarce, however, for online physics instruction,[9,10] with almost no published literature comparing measureable, objective educational outcomes in online and face-to-face physics laboratory courses.[11,12,13] The result could provide the makings of a "perfect academic storm" as physics departments feel pressured to provide online physics courses with insufficient data on best practices and/or the benefits and pitfalls of competing online education strategies, especially with regard to online physics laboratories.

The American Association of Physics Teachers (AAPT), in a position paper on physics labs, lists the following as goals for introductory lab programs: 1) engage students in the experimental process, including experimental design, 2) develop experimental and analytic skills, 3) advance conceptual learning, 4) assure that students "understand the role of direct observation in physics and to distinguish between inferences based on theory and the outcomes of experiments," and 5) develop collaborative learning skills.[14] Anecdotal evidence and informal survey responses suggest faculty are concerned that online laboratory learning may equate to the substitution of simulations for traditional laboratory experiences or the elimination of lab experiences altogether, mitigating against AAPT goals 1, 2, and 4. In this effort it is shown, however, that online laboratories that include hands-on, student directed, student implemented experimentation could meet all of the AAPT's stated goals, within the constraints for cost, technical rigor, and accuracy appropriate for an undergraduate-level introductory physics course.

This paper proceeds in three parts. Part 1 describes two surveys; the first assesses the current level of availability of introductory physics courses and labs in fully-online formats, and the second identifies the methods used to provide online physics laboratory experiences. Part 2 explores the feasibility of developing a set of "hands-on" student centered physical experiments that could meet the AAPT Guidelines and be deployed in a fully-online undergraduate physics laboratory course. Part 3 examines the initial results of using a subset of these experiments, both in a traditional face-to-face laboratory and as fully online exercises. Finally, "lessons learned" from the process are documented, as well as conclusions and recommendations for next steps in the development of a research-based online physics laboratory curriculum.

Part I: Surveys

According to the US Department of Education, there were 4495 post-secondary degree-granting institutions operating as of 2010, the most recent year reported.[15] In a previous effort, the author conducted a proportionate survey of 398 of those institutions offering undergraduate introductory courses in physics, to assess the level of availability of fully-online introductory physics courses and laboratories. The ratio of two-year to four-year institutions was approximately the same as the ratio of two-year to four-year public institutions for the same period. The survey results revealed that, of the 398 institutions offering introductory undergraduate physics courses, 38 (9.5% ± 2.9%, to the 95% confidence level) offered at least one similar physics course online, and of those, approximately half (15, or 3.8% ± 1.9%, to the 95% confidence level) offered the corresponding laboratory course, or the lab portion of the same course, in an online format.[4] These data indicate that physics courses have significantly lower incidence of online offerings, compared to all other disciplines reported by Allen *et al.*[1,2] Further analysis of the survey data showed no statistically-significant dependence of the results on the status of the institutions as two-year or four-year colleges/universities.

In this current effort, a similar survey was conducted of 311 accredited two-year institutions offering introductory physics courses in traditional (face-to-face) formats, to assess the changes in availability of introductory physics instruction online from Spring 2010 to Spring 2012. Results were further broken down by the type of introductory course (conceptual, algebra/trigonometry based, calculus-based). Broad courses in physical sciences, as well as courses in astronomy, meteorology, oceanography, geology, and/or earth sciences were excluded. Course schedules for the Spring 2012 semester for each institution were reviewed to identify the physics courses taught by type, as well as the modalities by which the courses were offered (self-reported by the institutions as classroom, hybrid, or online/web-based). The results showed a small but statistically significant increase in the availability of online physics courses and laboratory classes, with 34 (11% ± 3.5%, to the 95% confidence level) reporting at least one available section of introductory physics offered online and 21 (6.8% ± 2.8%, to the 95% confidence level) offering at least one section of an introductory physics laboratory course in a fully online format. Even with this increase, the results still demonstrate physics significantly lagging all other disciplines reported in the availability of online educational opportunities.

Because the total sample population of schools offering physics courses online was relatively small (34 institutions), a third survey was conducted. The third survey targeted only those institutions offering introductory physics courses fully online, and sought to identify the methods through which the corresponding laboratory content is presented. The second and third surveys were combined to provide a sample of 66 non-duplicative institutions offering or planning to offer fully-online introductory undergraduate physics courses within the next two years. At 26 of the 66 institutions, all corresponding laboratory work is required to be completed on-site at the campus. Students must either attend a traditional on-campus laboratory course, and so complete discussion and instruction online but perform experiments on-campus (web hybrid approach), or attend an on-campus week or weekend laboratory intensive to perform multiple lab exercises in a condensed time ("boot camp" approach). Thus, for these institutions (39% ± 12%, to the 95% confidence level of institutions offering introductory physics courses online), students complete identical experiments, with identical equipment and supervision, as their peers taking physics courses in a traditional format. The other 61% of online physics students (± 12% to the 95% confidence level) experience a variety of non-traditional approaches towards achieving the goals and learning objectives of the laboratory portion of the curriculum.

Besides traditional (on-site) physics labs, the third survey identified four additional categories into which these approaches fell.

The first approach identified was **video analysis** of instructor-supplied videos of experimental procedures. In some cases, the videos showed instructors performing the experimental procedure, with the measurement data either read by the instructor or the measurement device displays shown in the video for students to read. Other approaches to video analysis included an instructor-supplied video of an object in free-fall, or 'launched' in ballistic motion. The students then used commercially-available or educational-commons video analysis software to determine the position, velocity, and acceleration of the object as a function of time.[16] In each case, the student was removed from the experimental design and the hands-on aspects of the experimentation.

The second approach identified was the use of **virtual labs**. In this case, students performed laboratory exercises using a model of the actual physical phenomena, or "virtual" instrumentation that the students were required to manipulate on a computer screen.[17] Respondents were divided between using publically-available simulations, such as those developed

by the Physics Education Technology (PhET) Project at UC Boulder,[18,19] privately-developed simulations, or a combination of the two.

The third approach identified was direct, **hands-on** student experimentation performed off-site. Students purchased or borrowed equipment from the institution, or purchased materials from commercial sources, to perform experiments at home. Commercially-available equipment was either purchased as a "kit" from a specialty supplier, or acquired by student purchase of readily-available household items. Of the off-campus lab approaches, this one most closely mirrored the methods and degree of student involvement in the experimental process of the traditional on-campus labs.

The final approach identified was the use of **remote labs**. In this approach, students operate laboratory equipment directly through Internet-based remote control, with real-time video cameras providing direct feedback and immediate observation of measurements and results. A standard approach to distance learning in the engineering community during the past two decades,[20,21] remote labs are only beginning to enter the mainstream of physics education.[22]

A more detailed analysis of the survey results showed that nearly all institutions offering online physics laboratories used a combination of two or more of these approaches. Only four of the nearly four hundred total institutions surveyed across Surveys I and II identified online physics laboratory courses that consisted of simulations only. Thus, the overwhelming majority of introductory physics laboratory students, both in traditional face-to-face lab courses and in online lab courses, experience direct, hands-on experimentation with physical phenomena and measurement techniques.

Part II: Kit Development

For the second part of this effort, the "kit" approach to hands-on, direct experimentation in an online format was chosen for further development. Experiments were considered based on specific standards for cost and appropriateness. These standards limited consideration to experiments that 1) were relevant in scope and content to the curriculum of a first-semester introductory physics course, 2) were of appropriate complexity and depth for a college-level course, 3) would provide sufficient accuracy for student analysis and student satisfaction, 4) could be accomplished semi-autonomously by college students in a distance format (*e.g.*, from home, communicating with instructors via e-mail or

online chat, only), 5) required direct, hands-on interaction by students with the experimental process, and 6) could be accomplished with inexpensive or readily available materials at a total cost to students for ten such experiments commensurate with the price of a single textbook. The fact that ten post-secondary institutions offering "kit"-based hands-on online introductory physics laboratory courses were identified in the surveys, with average price-to-student of $130 for an equipment kit, showed immediately that the cost and content goals of this effort were within the current state-of-the-art.

A first-semester introductory physics course usually covers the topics of kinematics (velocity, acceleration, one- and two-dimensional motion, free-fall, and projectile motion), mechanics (Newton's Laws, forces and equilibrium, torques and rotations, gravity, conservation of energy, conservation of momentum), thermodynamics (ideal gas behavior, heat capacities and calorimetry, phase change, thermal transport, simple engines and efficiencies), fluids (hydrostatic and Bernoulli's equations, Archimedes' principle, viscosity, relationships of pressure, force, volume, and density), and simple harmonic motion and waves. A first-semester physics laboratory course typically includes eight to ten experiments, covering a cross-section of topics from this set. A selection of ten experiments covering this material, with an average equipment cost of $15 per experiment, would meet this effort's goals for appropriate content and cost commensurate with the price of a typical college textbook.

According to comments expressed in the Part I surveys, the primary objection by faculty to offering undergraduate physics laboratory courses online is the perceived lack of hands-on interaction by students with appropriate lab equipment. The sophistication of equipment currently available to the average college-aged online learner, however, far exceeds the level available at most college campuses just 30 years ago. All online learners, for instance, have access to a computer with an Internet connection, and the overwhelming majority of these have sound cards that sample at a standard rate of 44.1 kHz, far higher than the sampling rate of high-end introductory physics laboratory data acquisition systems. Coupled with a standard audio input device (microphone), the computer sound card provides students with the capability to time experimental events to within a few thousandths of a second.[23]

A standard computer soundcard, microphone, and collection of free software were used in experiments for this effort as a timing system accurate to one one-thousandth of a second or better. An open-source,

General Public Use sound recording and editing software product called Audacity[24] was used to audio-record experiments and determine the time intervals between different experimental events. Figure 1 shows a screen shot of an Audacity recording of a golf ball being dropped from a known height at the same instant the person holding the golf ball said the word, "Time." The start of each event (the word and the sound of the golf ball hitting the floor) is clearly seen in the recording track shown. Figure 2 shows a zoom-in window of the sound of the ball hitting the floor. Zooming in allows accurate reading by the software user of the precise time of the event. A subsequent reading of the time for the start of the drop allows a very accurate determination of the difference between the two; *i.e.*, the time for the golf ball to fall the known distance. Trials of this simple approach in a home environment yielded very consistent results, with calculation of the acceleration due to gravity repeatedly achieved to within 2% of the accepted value.

A second experiment was completed using the same timing method to investigate the principle of Conservation of Energy. A common first-semester physics experiment uses a motion detector to measure the heights of consecutive bounces of a ball. The ratio of the heights of consecutive bounces is related to the Coefficient of Restitution (COR), a measure of the mechanical energy dissipated in the collision of the ball with the floor. By Conservation of Energy, the ratio of consecutive bounce heights can be calculated using the ratio of the velocities of the ball before and after it bounces. By application of simple kinematics (ignoring air resistance), this quantity is also related to the ratio of time between consecutive bounces.

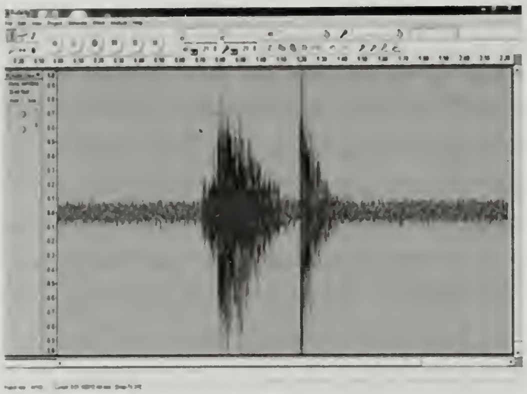

Figure 1. Recording of the time of free-fall for a ball released from a known height. First and second sounds shown are the release and end of flight, respectively. Data recorded with standard PC microphone, soundcard, and Audacity audio recording and editing software.

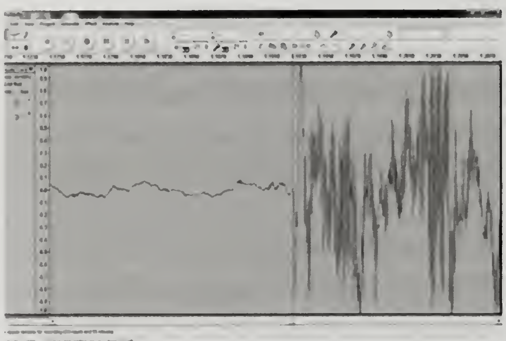

Figure 2. Zooming in to one sound event permits the time to be read to one ten-thousandth of a second.

In the second experiment, the Audacity software and computer sound card were used to determine the COR, and from this, determine *g*, the acceleration due to gravity.[25] The sounds of three consecutive bounces of a golf ball dropped from a known height were recorded using the Audacity software. The absolute times of each bounce were used to determine the time interval between the first two bounces and the time interval between the last two bounces. The COR was calculated from the ratio of these intervals. The timing information was also used to calculate the velocity immediately after the first bounce. Relating this to the initial potential energy and the percent of mechanical energy dissipated in the collision (determined from the COR), the acceleration due to gravity was determined. In trials in a home environment, this method consistently produced measurements of '*g*' within 1% of the accepted value.

These first two experiments investigated the topics of free-fall in constant acceleration, the kinematic equations, conservation of energy, and inelastic collisions. The experiments were completed in times commensurate with standard on-campus physics labs. Total estimated costs for all equipment required for both experiments (one golf ball and a measuring tape) was under $4. These experiments met or exceeded the goals for online introductory physics experiments, identified at the start of this effort.

While cell-phone texting has become the bane of undergraduate face-to-face instruction, the explosive growth and fierce competition in the cell phone industry provides great potential benefits to online learners. About 90% of all Americans aged 18 to 34 own a cell phone,[26] with cell phones increasing in the frequency and quality of applications offered. Almost all cell phones now include a stopwatch feature with one one-hundredth of a second resolution. Many newer devices also embed digital still and video cameras with resolution of up to 30 frames per second.

Combining cell phone video recording with readily-available free software for screen capture and frame-by-frame playback provides another method for accurate experimentation in the home environment. In the third home experiment performed for this effort, a kitchen table was tilted by placing two identical telephone books under the legs on the table's longer side. A low-friction toy hovering on an air cushion[27] was given an initial horizontal velocity on the table top, and the toy's motion was recorded using a cell phone camera. Figure 3 shows the motion of the toy in a series of frame-by-frame screen shots.

The video of the toy's motion was imported into Tracker,[28] an open source software product made available freely for non-commercial, educational purposes. The software allows the user to identify the location of an object of interest in each video frame, and use the pixel count and a reference length to map this location into a calibrated x-y coordinate system. Data can be exported and copied into other programs, or graphed and processed within Tracker to determine linear and angular velocities, accelerations, and momenta. Figure 4 shows screen shots of the resulting video and corresponding graphs of x- and y-locations versus time for the toy. Note the constant velocity of the object in the horizontal direction, with a clearly parabolic graph for the vertical data.

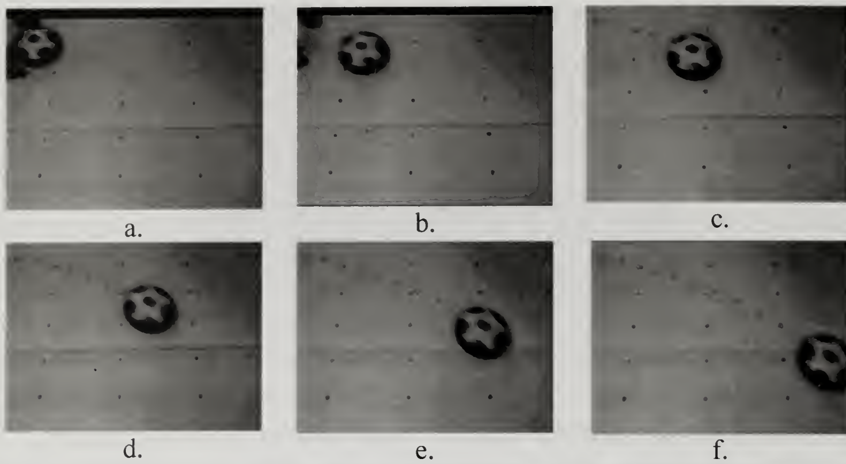

Figure 3. Motion of a frictionless toy given an initial horizontal velocity across a tilted table

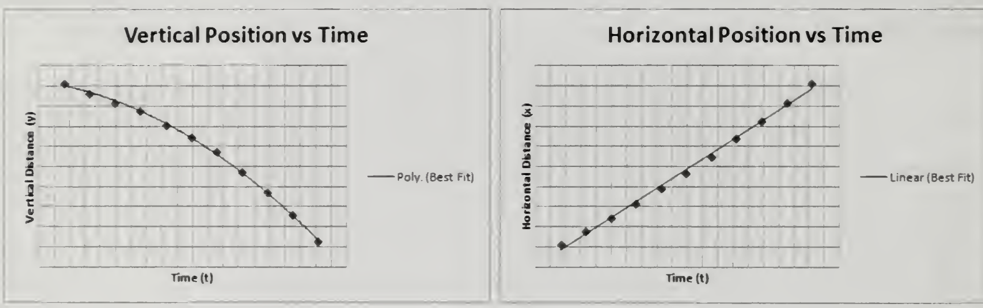

Figure 4. Position data for projectile motion, interpolated using Tracker video analysis software. Notice the constant horizontal velocity (linear graph of x-vs-t) and constant vertical acceleration (parabolic graph of y-vs-t).

Video analysis can be used in a wide range of introductory physics lab applications. Starting the toy from the lower left corner of the table, for instance, would allow the determination of the initial velocity and angle, while trigonometry and the kinematic equations could be used to predict the total distance traveled and x- and y-components of velocity at subsequent positions. Releasing a ball from rest and allowing it to roll down the table in a straight line from top to bottom would mirror the behavior of an object in free-fall. In a variation on this last approach, a single AA battery was released from rest and allowed to roll down the length of the table under the influence of gravity, then compared to the behavior of other rolling objects. An inexpensive caliper would permit the correlation of the accelerations to the objects' moments of inertia.

One of the factors limiting the cost and accuracy of the commercially-available kits was the high prices of calibrated weight sets. Most kits used less-accurate, less-expensive spring scales instead, or a very limited number of calibrated weights. A review of commercial laboratory supply vendors found calibrated weight sets typically costing \$50 to \$70, with a single vendor offering a lowest price of \$25 for a set of hooked masses. Digital scales developed for the jewelry business, with capacity suited for lab applications and resolution of 0.1 grams, however, are now available for under \$20.[29]

With the growing availability of digitized consumer products, such as video cameras, timing devices, software, and scales, the quality and accuracy of home laboratory experiments are now only limited by the creativity of the physics lab instructor. In addition to the free and low-priced items already described, a list was put together of equipment available from multiple vendors and suited for use in home experimentation for a web-based introductory physics course. The final list included a measuring tape, several balls and steel bearings, a plastic caliper, a digital scale and calibration mass, wood blocks and screw-in metal eye hooks, a 1.5 ft. section of 1 x 6 board, 2 spring scales, an edge pulley and table clamp, a stand and right-angle clamp (two preferred), a tandem pulley, a balance stand and three knife-edge meter-stick clamps, a graduated cylinder, an aluminum calorimeter, thermometer measuring −12 °C to 100 °C, a syringe (without needle) and Luer lock cap, two springs, a half-meter stick, a protractor, a spool of thread or string, a push-pin, paper clips, fishing weights, tape and scissors. With the software and techniques described above, this equipment could be used by online students to perform more than twenty college-level experiments spanning the entire range of topics covered in a first-semester introductory physics course. A review of prices offered through a limited number of laboratory equipment suppliers resulted in a price estimate for the entire equipment list of about \$170. Additional cost savings could be realized by economies of scale and by reducing the number of experiments from twenty to eight or ten.

Part III: Student Trials

In the third part of this effort, the first two experiments described in detail in Part II were developed and tried with undergraduate students in an introductory algebra/trigonometry-based physics lab course. The results provided insights into both the strengths and the weaknesses of the chosen approach.

In the first trial, students in a traditional face-to-face physics laboratory course completed two experiments for extra credit at home in a simulated online environment. All descriptions of procedures and techniques for the lab exercises were delivered online, and students were only permitted to communicate with the instructor regarding the experiment via online means (chat, email, virtual office hours). This assured adherence to the "do no harm" philosophy, as students' primary lab learning experience remained unchanged.

Students were provided with a brief tutorial on how to use the Audacity software and given access to written experimental instructions/guidelines. Initial results were astoundingly poor, as students asked questions at a staggeringly low rate, despite instructor availability through scheduled online virtual office hours, chat, and email response times under two hours. Misunderstandings, misconceptions, and computational errors resulted in student-demonstrated percent errors ranging from 2% to 35%, despite consistent achievement of experimental errors of 1% to 2% in the same experiments carried out by the instructor.

As a result of the initial trial, the entire approach to online laboratory development was restructured. First, the simulated online environment was found to be inefficient as a primary means for vetting student experiments for use in an online laboratory course. Student misconceptions only became apparent once a semester, and only after final experimental reports were submitted. A second approach was developed in which students were supplied written and video instructions, then performed the experiments on campus under direct instructor supervision, but with limited/no instructor comment or direction. Direct instructor observation and immediate student feedback helped identify areas where instructions were unclear, with the result that instructional materials could be modified, improved, and retested within the week.

Video instructions were developed to supplement the written experimental instructions for one of the pilot experiments. These instructions included animations to explain the underlying physical phenomena. Care was taken to make sure the video instructional tools directly addressed the most common misconceptions and questions students had in the performance of the experiments. The goal was to provide instructional information and background sufficient to allow students to make educated choices in measurement methodologies and analyses, to improve experimental accuracy and validity of conclusions, and to assure students could connect the experiments to their prior

textbook/theoretical learning, all with minimal/no direct student-instructor guidance.

In addition to the revised video tutorials, the written materials were redesigned to include interactive questions for students to answer based on watching the video materials and performing experimental steps. A sample set of data was provided, with one modeled calculation, to further clarify the analytic process. Additionally, students were required to participate in the derivation of the relevant formulas through a guided process (written instructions provided some steps, students provided subsequent steps).

In the second and third trials, conducted in a traditional on-campus setting with Instructor supervision, students were given the revised instructional materials one week in advance of the scheduled experiment, and were specifically warned that no questions would be answered that had been directly addressed in the written or video presentations. The outcomes included dramatic improvements in student preparedness (as measured by Instructor observation), student conceptual understanding and confidence (as determined from student feedback), and experimental accuracy (as measured in laboratory reports submitted for grading).

Lessons Learned and Next Steps

Animated theoretical background information and visual lab instructions provide students a significant advantage in preparing for, understanding, and performing lab experiments. They also help students directly tie their textbook knowledge to a practical, physical application. As a result, additional visual lab instructional materials will be developed, for both online and face-to-face implementation.

Beginning physics students with no more than a rudimentary background in algebra and trigonometry are capable of deriving physical formulae for lab applications. This process also helps them understand the significance of the formulae, and how they relate to the theoretical/textbook knowledge they already have. However, students at this level need considerable guidance in this process. Lab instructions should therefore be modified incrementally to include (either through a pre-lab exercise or as part of the in-class lab experience) a guided partial derivation of some of the relevant formulae.

A faster, more efficient methodology was identified for pilot testing of new labs for distance education. In this method, candidate experiments for distance labs are vetted in the traditional classroom, with a competent instructor monitoring and noting the common mistakes and

misconceptions in real-time, with limited instructor interaction and re-direction. New labs can then be implemented in a simulated or 'real' online environment only after they have been dry-run in class, with modifications of the lab methods and instructions based on the initial in-class tests. Student use in a fully-online environment is still required as a "Next Step" for the full development of the lab exercises explored in this investigation.

The greatest hindrance to the development and improvement of a fully-online physics laboratory program is the lack of objective assessment standards for research-based guidance of the curriculum development process. Objective assessment criteria must be developed to compare the efficacy of competing lab methodologies, for both online and on-campus implementation. Assessment criteria should be informed by the AAPT goals for introductory laboratories[14] and the findings of the National Academies. [30] Correlations should be monitored between different laboratory instructional methods and student retention in the lab course, persistence into follow-on courses, improvements in conceptual understanding, knowledge of the scientific process and methods, and perceptions of and interest in further scientific investigation.

Conclusions

Online learning opportunities abound. Online access to introductory physics courses and labs, while far behind the level of accessibility in other disciplines, is following the same general trend in growth. Multiple methods already exist and are being used to provide undergraduate introductory laboratory programs in a fully-online format. Improved quality in and access to consumer electronics, innovations like the use of video and remodeled laboratory instructions, and student demands for flexibility in scheduling and accessibility will continue to impact the future of the online lab experience.

The quality of the lab program that will emerge in the online arena is entirely up to the physics education community. As said in the AAPT Policy Statement,[15] "Excellent laboratory programs do not happen by chance but require thought and planning. Achieving these goals is a worthy challenge, and their broad implementation will require the best efforts of the physics community." Rigorous, objective metrics must be devised so that competing online laboratory approaches can be evaluated and improved. Research-based assessments must be interwoven into the development of online physics laboratory programs. The alternative is to

accept the dramatic growth in the availability of online laboratory programs, with no objective measure of their educational value or impact on future science learning.

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[1] "Going the Distance: Online Education in the United States, 2011," I. Elaine Allen and Jeff Seaman, Babson Survey Research Group, ISBN 978-0-9840288-1-8, November 2011

[2] "Growing by Degrees: Online Education in the United States, 2005," I. Elaine Allen and Jeff Seaman, The Sloan Consortium, ISBN 978-0-9766714-2-8, November 2005

[3] Ibid

[4] Ann M. Reagan, "Development of a Fully Online Undergraduate Physics Laboratory Course," AAPT Winter Meeting, Jacksonville, FL Jan 2011

[5] See, for example, *Phys. Rev. Special Topics - Phys. Ed. Res. (PRSTPER)*, an electronic-only journal devoted entirely to this subject, co-sponsored by the American Physical Society (APS) Forum on Education and the American Association of Physics Teachers (AAPT); http://prst-per.aps.org/

[6] David Hestenes, Malcolm Wells, and Gregg Swackhamer, "Force Concept Inventory," *The Physics Teacher*, **30** (3), 141-151 (1992)

[7] David Hestenes and Malcolm Wells, "A Mechanics Baseline Test," *The Physics Teacher*, **30** (3), 159-166 (1992)

[8] Richard R. Hake, "Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses," *Am. J. Phys.*, **66** (1), (Jan 1998)

[9] Gerd Kortemeyer, "Correlations between student discussion behavior, attitudes, and learning," *Phys. Rev. ST- PER*, **3**, 010101 (2007)

[10] Ronald Thornton, "Web-Delivered Interactive Lecture Demonstrations: Creating an active science learning environment over the Internet," *APS FEd. Newsletter*, Fall 2003

[11] P. Le Couteur, "Review of Literature on Remote and Web-based Science Labs," BCCampus Articulation and Transfer of Remote and Web-based Science Lab Curriculum Project, June 6, 2009
http://rwsl.nic.bc.ca/Docs/Review_of_Literature_on_Remote_and_Web-based_Science_Labs.pdf (February, 2012)

[12] Anne J. Cox and William F. Junkin III, "Enhanced Student Learning in the Introductory Physics Laboratory," *J. Phys Ed.*, **31** (1), (Jan. 2002)

[13] N. D. Finkelstein, *et al.*, "When learning about the real world is better done virtually: A study of substituting computer simulations for laboratory equipment," *Phys. Rev. ST-PER*, **1**, 010103 (2005)

[14] "Goals of the Introductory Physics Laboratory," American Association of Physics Teachers (AAPT), *The Physics Teacher*, **35**, 546-548 (1997)

[15] "Digest of Education Statistics," Table 276, National Center for Education Statistics, Department of Education, 2010

[16] *e.g.*, see Edward P. Wyrembeck, "Video analysis with a web camera," *The Physics Teacher*, **47**, 28-29 (Jan 2009)

[17] *e.g.*, see R. W. Tarara, "Photo-Realistic Laboratory Simulations," made available for free educational use by the developer at
http://www.saintmarys.edu/~rtarara/software.html (2012)

[18] Noah D. Finklestein, *et al.*, "High-Tech Tools for Teaching Physics: the Physics Education Technology Project," *J. of Online Teaching and Learning*, **2** (3) Sep 2006

[19] The simulation collection of the University of Colorado at Boulder's Physics Education Technology project may be accessed at http://phet.colorado.edu/en/simulations (2012)

[20] James P. Trevelyan, "Lessons learned from ten years experience with remote laboratories," Proceedings of the International Conference on Engineering Education Research, Olomouc, Czech Republic, 2004; available online at http://www.ineer.org/Events/ICEER2004/Proceedings/papers/0687.pdf , as of February 2012

[21] Euan Lindsay, Som Naidu, and Malcolm Good, "A Different Kind of Difference: Theoretical Implications of Using Technology to Overcome Separation in Remote Laboratories," *Int. J. Engng Ed.*, **23** (4), 772-779 (2007)

[22] B. Alhalabi, D. Marcovitz, K. Hamza, and S. Hsu, "Remote labs: An innovative leap in the world of distance education," *Proceedings of The 4th World Multiconference on Systemics, Cybernetics and Informatics (SCI 2000)*, Orlando, FL, July 23-26, 2000

[23] I. Stensgaard and E. Laegsgaard, "Listening to the coefficient of restitution – revisited," *Am. J. Phys.* **69**, 136-140 (1981)

[24] *e.g.*, see http://wiki.audacityteam.org/wiki/About_Audacity (Mar 2012)

[25] C. E. Aguiar and F. Laudares, "Listening to the coefficient of restitution and the gravitational acceleration of a bouncing ball," *Am J. Phys.* **71** (5), 499-501 (May 2003)

[26] "Young Consumers Want Cell Phone Features," Marketing Charts online journal, Watershed Publishing, http://www.marketingcharts.com/direct/young-consumers-want-cell-phone-features-13278/ (Jun 2010)

[27] Air-Puck Soccer, Schylling, Inc, Rowley, MA: $9.99 retail

[28] Tracker, developed by D. Brown of Cabrillo College, Aptos, CA, may be downloaded for free at http://www.cabrillo.edu/~dbrown/tracker/ ; update 2010

[29] *e.g.*, see http://www.wholesale-scales.com/index.php?main_page=product_info&products_id=382 (2012)

[30] "America's Lab Report: Investigations in High School Science," Committee on High School Science Laboratories: Role and Vision, National Research Council, Susan R. Singer, Margaret L. Hilton, and Heidi A. Schweingruber, editors, National Academies Press, 2005, ISBN 9780309139342

Perspectives from the field: Partnerships for Diversifying and Improving Ecology Education

Teresa M. Mourad

Ecological Society of America

While the National Science Foundation (NSF) serves a critical role in supporting basic and applied research in the natural and social sciences, NSF has long recognized and supported efforts in Science, Technology, Engineering and Mathematics (STEM) education at all levels both formal and informal. These investments integrate research with education, challenge barriers to participation, and often foster partnerships among otherwise unlikely friends.

Between 2006 and 2010 the Ecological Society of America (ESA) received several NSF awards for its priority education initiatives. As the largest professional community of ecologists in the world, ESA has made a commitment to diversifying the field of ecology and promoting outstanding ecology education to advance the understanding of life on Earth.

To this end, ESA's primary initiatives have focused on two core activities, and recently a significant project to engage a wide variety of stakeholders interested in environmental literacy. NSF funding has been used to support: 1) the Strategies for Ecology Education, Diversity and Sustainability (SEEDS) mentoring program, 2) partnerships to facilitate the discovery of digital resources for learning through EcoEd Digital Library and 3) an Ecology and Education Summit to develop an Action Plan that will accelerate Environmental Literacy for a Sustainable World.

SEEDS Mentoring Program for Diverse Undergraduate Students

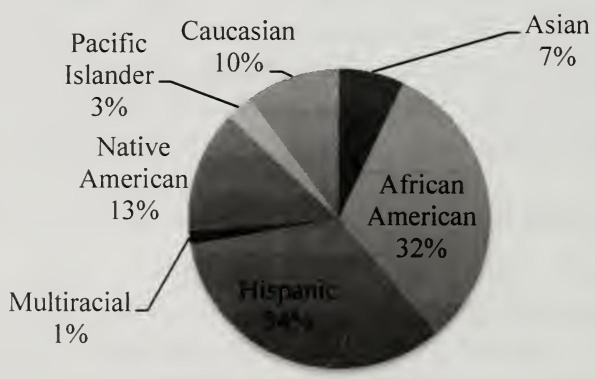
Focused on the undergraduate level, the SEEDS (http://esa.org/seeds) program began in 1996 with substantial funding from the Andrew W. Mellon Foundation. The program initially served African American students and faculty at selected Historically Black Colleges and Universities (HBCUs). Activities were led by the Institute of Ecosystem Studies (IES) in partnership with ESA and the United Negro College Fund (UNCF). In 2002, ESA assumed full management of SEEDS and since then, has expanded its range of student activities to include travel scholarships to ecological field trips, ESA Annual Meetings, undergraduate research fellowships and leadership meetings and currently serves all racial and ethnic students.

In many institutions where large numbers of minority students are enrolled, the subject of biology and its supporting funding and infrastructure is often skewed in favor of biomedical careers.

In order to increase the numbers of minorities seeking careers in ecology, the SEEDS program addresses two key barriers to recruitment and retention: 1) the need for mentors and 2) the lack of awareness of ecology as a viable course of study and career opportunity (Baker 2000; Committee on Underrepresented Groups 2011; Klug *et al.* 2002).

The mission of SEEDS is to diversify and strengthen the profession of ecology through opportunities that stimulate and nurture the interest of students underrepresented in ecology and to develop diverse leadership for future generations. Since 1996, the program has served an estimated 3,000 people in a variety of program opportunities. Direct support was offered to 488 students between 2002-2011 through ecological field trips, Leadership Meetings (since 2006), Travel Awards to ESA Annual Meetings, and Undergraduate Research Fellowships. Forty percent of these students were served more than once, reflecting the nurturing philosophy of SEEDS. Figure 1 shows the diversity of students served by racial / ethnic categories.

Figure 1.
SEEDS Students Served 2002-2011
By Race/Ethnicity



In addition to these opportunities, SEEDS also built up a campus ecology chapter network. There are now 73 campus chapters across the country and three high schools. ESA offers a small grants and special projects grants program. In 2010, SEEDSNet, a social networking site, was launched, offering forums, virtual career fairs and webinars.

The program relies on multiple layers of mentoring support: ESA members who are established scientists, SEEDS alumni graduate students and SEEDS undergraduate students who are connected with high school students. ESA also has two full time staff dedicated to the program who maintain communications with the entire network through e-newsletters, announcements, job posts on SEEDSNet and facilitating webinars and workshops led by students.

NSF funding has provided critical support for the biannual ecological field trips in cooperation with the Long Term Ecological Research (LTER) sites, the Leadership Meetings, travel awards for 13-15 students per year to ESA annual meetings and most recently, the 2012-2013 cohort of Undergraduate Research Fellows. SEEDS was awarded the 2006 *Presidential Award for Excellence in Science, Mathematics, and Engineering Mentoring* (PAESMEM), the highest award of its kind in the nation, administered by the NSF. Other sources of funding for the SEEDS program include the Andrew W. Mellon Foundation, the US Forest Service, the David and Lucile Packard Foundation and the generous contributions of ESA members.

Impact

A 2011 survey of SEEDS participants directly served (N=85) shows that 51.7% have graduated, 42.35% are in graduate school (N=36), 50.59% are employed (including students). Of those in graduate school, 97% (N=35) are still in an ecology or environment-related field. Of those who are employed, 93% have remained in the field, indicating positive career impacts of SEEDS. Further, 98% indicated they plan to remain involved in the environmental field in the future. SEEDS has played a critical role in retention of underrepresented minority students by providing support through an active social network especially for those students in institutions who are isolated from their own communities.

The survey showed that 63.1% of respondents felt that SEEDS had "a lot" or a "great deal" of influence on their decision to pursue their careers. Another 23.8% indicated that SEEDS had "somewhat" of an influence. The top three ways in which SEEDS contributed to their career choice were (N=82): 1) Exposed me to broader career options in the ecology field (75%) 2) Provided me with leadership skills/confidence to lead (69.5%) and 3) Helped me understand the strength of diverse perspectives (64.6%). Additionally, 57.4% of respondents indicated that SEEDS "most definitely" influenced or had "a lot of" influence on their seeing themselves as leaders.

Digital Resource Discovery and Dynamic Learning Communities for a Changing Biology

While SEEDS focuses on student development, the Digital Resource Discovery (DRD) project focuses on faculty teaching needs. In 2011, ESA was awarded a grant from the National Science Foundation titled: Digital Resource Discovery and Dynamic Learning Communities for a Changing Biology (DRD). This project was developed as a partnership among the Ecological Society of America (ESA), the Botanical Society of America (BSA), the Cornell University Lab of Ornithology (Science Pipes), the Society for the Study of Evolution (SSE), and the Society for Economic Botany (SEB).

ESA's longstanding EcoEd Digital Library (EcoEdDL – http://ecoed.esa.org) serves as the DRD project's testbed for development. EcoEdDL is built on the CWIS platform developed by the Internet Scout team at the University of Wisconsin–Madison, which has many Web 2.0 features built in. EcoEdDL resources are harvested by the BioSciEd Net (BEN) which is a pathway for biology education resources in the National Science Digital Library (NSDL). All EcoEdDL resources are peer-reviewed prior to publication.

DRD project activities involve four components: 1) technology development, 2) integration with a data visualization tool, Cornell's Science Pipes, 3) community engagement and; 4) sustainability planning. The four components were guided by an NSF-funded workshop in 2010 where ESA brought together educators, scientists, technology experts and potential partners to explore the role of EcoEdDL in *Translating Research for Undergraduate Ecology Education.*

The DRD project was designed to respond to four demanding challenges which emerged:

1. Demand for Quantitative Skills in Biology
2. Demand for Digital Resource Discovery Services
3. Demand for Community Support Services
4. Demand for a Sustainable and Innovative Digital Library and Learning Community.

Increasingly, dramatic developments in the biological sciences draw attention to understanding the highly interconnected nature of environmental and biological systems. (AAAS 2010; NRC 2009; NSF 2009). These developments highlight the importance of understanding

research data, particularly large datasets across spatial and temporal scales.

Overwhelmingly, faculty asked for support and tools to provide students with authentic and meaningful opportunities for a 21st century ecology classroom to collect, analyze, visualize, and interpret real data. Faculty saw that EcoEdDL could play a large role in facilitating the development and dissemination of classroom resources in the face of technical and logistical challenges for working with datasets and a scarcity of relevant user friendly tools. This is being developed through our partnership with Science Pipes.

Through separate NSF awards, ESA also developed an Interactive Conceptual Framework to support Education using Continental-Scale Data. Rich with definitions, links to datasets and resources, this framework was one of the outputs in ESA's initiative to develop a strategy that will introduce the opportunities and the data to be available from the National Ecological Observatory Network (NEON) to the educational community and to engage faculty from Historically Black Colleges and Universities and Minority-Serving Institutions. As an extension of the project, ESA brought together undergraduate faculty from MSIs and primarily undergraduate institutions to develop a set of teaching activities using large scale data under the auspices of the National Center for Ecological Analysis and Synthesis (NCEAS). These resources, once peer-reviewed, will be available in EcoEdDL.

Going forward, ESA will also incorporate recommendations to:

1. build a recognition program that will that will promote credibility and value for education scholarship within home institutions and the wider community
2. position EcoEdDL as a vehicle for researchers to achieve NSF broader impacts requirements
3. develop strategic partnerships with research centers that have expert resources in many multimedia formats to develop leading educational products and services.

Accelerating Environmental Literacy for a Sustainable World

The growing momentum within the scientific and educational communities to break down the silos between disciplines, between research and education, and between formal and informal ways of learning has brought about a new appreciation of the need to work together. Going beyond ESA and the field of biology, ESA spearheaded the Ecology and

Education Summit (http://www.esa.org/eesummit/) in partnership with 22 national organizations. The Summit convened 200 people at the headquarters of the National Education Association in Washington, DC from October 14-16, 2010 on the theme, *Environmental Literacy for a Sustainable World.*

The event was co-chaired by Dr. Meg Lowman, ESA's Vice President for Education and Human Resources, and by Dr. Carolyn Breedlove, Manager of the National Education Association Green Across America, External Partnerships and Advocacy. Major funding came from the National Science Foundation, the USDA Forest Service, the USDA National Institute for Food and Agriculture and the National Oceanic and Atmospheric Administration.

Stretching across many sectors, the summit brought together diverse thought leaders, educators, scientists, professionals, and policy experts from a wide variety of sectors including academia, business, agriculture, government, health, and media, that serve the spectrum of grades K-20+ audiences.

The open-segment of the Summit featured two keynote speakers: Will Steger, Arctic Explorer and Will Allen, Urban Farmer, Growing Power, as well as 27 panelists and moderators on six panel discussions. Six pre-Summit events were also organized to broaden interest and participation. Summit participants also participated in two breakout sessions to generate recommendations.

The Summit was organized along five themes:

1) Learning about Complexity and Change: Foundations for Environmental Literacy
2) Turning the Tide: Building a Green Society through Learning and Doing
3) Seeing our World Inside and Out: Harnessing Technology for Environmental Literacy
4) Best Practices for Effective Teaching and Learning
5) Environmental Literacy for All

Following the open segment of the Summit, sixty-two invited participants mapped out a Decadal Action Plan that will provide direction for concerted action. Twelve action items were identified. These action items aimed at greater integration of the many existing programs and initiatives across the country. While not comprehensive, they draw attention to some strategic opportunities for the community to rally around

to foster an environmentally literate society. It is regarded as a living document and is expected to evolve and be updated over the decade.

Learning about Complexity and Change

Complexity and change recognizes the interdependent relationships among ecological, socioeconomic and cultural systems that are foundational to life on Earth. Participants called for an environmental literacy framework that will integrate the social dimensions into existing earth systems literacy frameworks.

Turning the Tide

Conscious of the present trajectory of unsustainable socio-environmental change, participants urged that initiatives catalyze grassroots efforts; that Green schools be developed as hubs for communities to live and learn about sustainability; and that an Action kit be created that communities can use for achieving a green society.

Harnessing Technology

The enormous reach of technology is evident in the volume of games sold and the near universal embrace of mobile technology today. The creation of "C.Science 2.0" focused on handheld games is a huge opportunity for environmental literacy efforts.

Best Practices for Effective Teaching and Learning

Participants recognized that there are a number of effective programs and felt a need for a centralized space that will pull best practices and resources across sectors and audiences. For K12 audiences, it is critical that we engage stakeholders at the state level - which can in turn impact the 15,000 school districts in a non-partisan fashion. This means strong networks at the state level with particular efforts to show how environmental literacy is positioned in education content standards and continued support for research on the effectiveness of environmental or sustainability education programs.

Environmental Literacy for All

The dramatic changes in our population demographics have forced us to confront the reality that to date, most efforts have largely failed to engage the diversity of audiences and communities in environmental education. Repeatedly, our panelists – representing media, health,

architecture, religion, and gaming fields – reminded us that we need to 'get the right vocabulary, the right audience, and the right message'. Relating environmental literacy to core American values like economic prosperity (jobs) and health is essential to reaching the broader society. In this effort, collaboration with the private sector is key.

Concluding Reflections

As a national nonprofit professional society, ESA's education programs are mission driven and attuned to the challenges and needs of the field. Professional societies are in a unique position to play vital facilitative roles on activities that require cooperative efforts. There is room for individual scientists to participate as well as for organizational partnerships. The grants from NSF has allowed ESA to address the challenge of broadening participation and retention of minority students, filling gaps in resource needs in a central repository of teaching resources, and prioritizing important decadal initiatives for environmental literacy – all accomplished through synergistic partnerships.

References

American Association for the Advancement of Science. 2010. *Vision and Change in Undergraduate Biology Education: A Call to Action*. AAAS, Washington DC. Last Accessed March 7, 2012 http://www.visionandchange.org

Baker, B. (2000). Recruiting Minorities to the Biological Sciences in BioScience. 50(3).191-195

Committee on Underrepresented Groups and the Expansion of the Science and Engineering Workforce Pipeline; Committee on Science, Engineering, and Public Policy; Policy and Global Affairs; National Academy of Sciences, National Academy of Engineering, and Institute of Medicine. 2011. *Expanding Underrepresented Minority Participation: America's Science and Technology Talent at the Crossroads*. National Academies Press, Washington DC.

Klug, M.J., J. Hodder, & H. Swain. (2002). Enhancing Educational Opportunities at Biological

Field Stations and Marine Laboratories. Michigan State University. Report of a Workshop, Education and Recruitment into the Biological Sciences: Potential Role of Field Station and Marine Laboratories, Washington, D.C. Last Accessed March 7, 2012 http://www.obfs.org/assets/docs/publications/hodder%202009%20undergraduates%20field%20stations.pdf

National Research Council. Committee on a New Biology for the 21st Century: Ensuring

the United States Leads the Coming Biology Revolution. 2009. *A New Biology for the 21st Century: Ensuring the United States Leads the Coming Biology Revolution.* Board on Life Sciences, Division on Earth and Life Studies. National Research Council of the National Academies. The National Academies Press. Washington, D.C. Last Accessed March 7, 2012 http://www.nap.edu/catalog.php?record_id=12764#orgs

NSF Advisory Committee for Environmental Research and Education. 2009. *Transitions and Tipping Points in Complex Environmental Systems*. A Report by the NSF Advisory Committee for Environmental Research and Education. National Science Foundation, Arlington, VA. Last Accessed March 7, 2012
http://www.nsf.gov/geo/ere/ereweb/ac-ere/nsf6895_ere_report_090809.pdf

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Editor's Comments

With this issue, I'm excited to begin my role as your new Journal editor.

The Academy expresses a hearty thanks to Jackie Maffucci for serving as Journal editor for more than two years, and I personally appreciated her help with the smooth transition in Journal editorship. We're also extremely pleased that Sethanne Howard continues as Associate Editor. We welcome Peg Kay as an Associate Editor.

This Summer issue provides some great Summer reading and perusing! For example, we include here a photo journal of the Academy's Awards Banquet in the Spring, as well as thoughts from your leaders, outgoing President Gerry Christman and incoming President Jim Cole.

The Academy's Awards Committee, chaired by Peg Kay, deserves many votes of appreciation for all its productive work towards the 2012 Awards Banquet. This year, the Academy had a most impressive line-up of awardees – the Distinguished Career in Science award, the Lamberton Award for Elementary and Secondary Education, and honorees from each of these fields: Behavioral Sciences and Social Sciences; Biological Sciences; Engineering Sciences; Mathematics and Computer Sciences; and Physical Sciences. The list was rounded out by a History of Science award and an award for Service to Science. Although space doesn't allow us to list the numerous outstanding accomplishments of the awardees, I'm sure you will enjoy perusing our 2012 photo journal in these pages. It provides undisputed evidence that the Washington, DC region is rich with scientific and intellectual resources.

We also have three notable papers in this issue. The paper by Paula Veiga will likely be of great interest to our audience of scientists who are not necessarily seasoned Egyptologists, forensic archaeologists, or geneticists. The article is about the study of mummies and it provides a sometimes graphic overview of the current developments and issues in this fascinating field of study. We hope it invites our readers to explore how they might learn more … and as a perfect starting place on the history of ancient medicine, we suggest checking out the Institute for the Preservation of Medical Traditions at http://medicaltraditions.org.

The paper by Bruce Furino provides insights into the first-hand experiences and perceptions of young students involved in a hands-on STEM education initiative administered by a major university in Florida –

the Internet Science and Technology Fair. This paper provides an interesting aggregated "snapshot" of the students who were part of the most recent fair, and we look forward to reading a planned multi-year evaluation in the near future.

The excellent article by Carl Mungan and John Denker is a classic applied physics paper that is of interest both historically and mathematically. A system that one might think simple to model (a ball in a musket) contains mathematical richness which is both surprising and fascinating.

As my new Editor role unfolds, I look forward to hearing from Academy members on their current wishes for the Journal. Thank you for this opportunity to be your Editor.

Sally A. Rood, PhD
Editor, *Journal of the Washington Academy of Sciences*

Studying Mummies and Human Remains: Some Current Developments and Issues

Paula Veiga

Anthropological Team, Luxor West Bank, Egypt

Abstract

This article discusses mummification processes, both natural and intentional, and presents a brief history of ancient Egyptian mummification procedures. The article then provides an overview of existing technologies for analyzing mummies, and the varied uses and applications of examining mummies. It also presents some background and issues related to mummy storage and display in museum environments. Given the ancient procedures used, the limitations of modern analysis techniques, and the existing problems trying to store and display mummies today, the article concludes by summarizing both the current challenges and benefits of the present-day study of mummies, and offering some cautions.

Introduction

This paper focuses on the task of retrieving information from human remains, with a particular focus on ancient Egyptian mummies. As the human body has not changed much in 5,000 years, information retrieved must be consistent with present human evolution status; traces of diseases still existing today should confer with contemporary specimens. Mummified bodies, regardless of their preservation condition when found, provide important pieces of information in the study of ancient medicine.

There is a designation often associated with mummified remains: the word mummy, that comes from the medieval Latin word *mumia,*[1] borrowed from the Arabic *mūmiyyah*, مومية, which also means *bitumen* – a substance thought in the past to have had medicinal properties.[2]

The Process of Mummification

Various environmental elements, if not controlled, accelerate mummification and transformation of a dead body.[3] These are: the growth of microbial organisms caused by moisture; the presence of food; the human remains themselves; the application of incense, oils and resins; and the effect of plant residues, minerals, and animal fats.

After the body has perished, it loses water, and gases start to form inside the body. Since human bodies are comprised of almost 70% water, the body starts to desiccate (dry) naturally. Environmental conditions may accelerate the reduction of water, release the gases, and start the putrefaction of the tissues. In Egypt, the extremely arid climate favors natural body desiccation.[4] In addition, an adipocere (fatty) substance can be formed and turn the body into a bloated specimen.

Other conditions affect the process after death, and cause the body to lose all its tissue and become skeletonized. These include extreme demineralization with decalcification of bones.

Some bodies are found with one or more of these conditions, depending on whether they were exposed or buried, depending on materials left next to the body, and depending on the amount of light, moisture and air ventilation conditions that were *in situ* over time.[5] Air exposure is crucial in mummification; well-ventilated spaces usually allow bodies to mummify (and desert winds have the same effect). Either hot or cold dry air is a mummifying factor, while moisture enables putrefaction and decomposition.

The presence of insects[6] usually accelerates body skeletonization. There is a specific fauna in the insect group, necrophagi insects, who feed on dead tissue. Several pupae and larvae from different species are often found in mummies, resulting in body decay.

Mummification in Egyptian History

In ancient Egyptian history, mummification started to happen naturally and spontaneously. Natural mummification of bodies[7] was a characteristic of Pre- (5300-3000 BCE) and Early- (3000-2686 BCE) Dynastic Egypt.[8] At first, the bodies were simply placed in the fetal position in shallow oval graves, usually surrounded by personal objects of their daily life.[9] The buried bodies of the deceased became mummified, although the majority of natural mummified bodies found are skeletonized bodies. The mummy called Ginger, housed at the British Museum in London, provides an example of a Pre-Dynastic body, naturally desiccated in the Egyptian sands.[10]

Intentional mummification with evisceration (disembowelment) started from the 4th Dynasty (2613 BCE) onward. The oldest bodies that have been recovered are from that period.

From the Middle Kingdom, 11th to 13th Dynasties (2055-1650 BCE), we have the example of the "Two Brothers" housed at the Manchester Museum. They were first analyzed by Margaret Murray in 1908 and more recently by Rosalie David who wrote about the tomb where they were found.[11]

Most of the bodies belonging to collections and available for study – such as the Royal mummies – are from the:

- New Kingdom (18th to 20th Dynasties, 1550 to 1069 BCE);
- Late Period (26th to 30th Dynasties, 664 to 332 BCE); and
- Greco-Roman Period (Ptolemaic 332-30 BCE and Roman 30 BCE-395 CE).

In Egypt, mummification started fading as a funerary practice in the 7th century CE,[12] probably as a result of the influence of Islam.

Mummification Procedures Used in Ancient Egypt

The techniques developed by ancient Egyptians for mummifying humans were intended to provide the best preservation possible. The materials used, techniques employed, and objects that accompanied mummified bodies are all important and should be considered.

In Dynastic Egypt (3000-332 BCE), coffins appeared to arrest body decay from the artificial process of mummification.[13] In order to prepare bodies for the afterlife, the lungs, intestines, stomach, and liver were removed and preserved in jars, and linen wrappings were tightly fastened to the whole body. The heart was also removed from the chest cavity, but it was treated with unguents, and returned to its anatomical location, usually shielded by a scarab depicting Chapter 30 from the Book of the Dead, for protection in the afterlife.

Up to 12 or more layers of linen bandages can be found on an Egyptian mummy. An optimal mummification procedure would involve changing the linen several times up to 70 days[14] to eliminate all moisture from the body.

Natural factors and ingredients such as dry soil, wind and salt contribute to preserving a dead body from deterioration. The salt used to intentionally dry up bodies in ancient Egypt was natron[15] retrieved from the regions of Wadi Natrun and el-Kab in Egypt, which have natural deposits of this desiccation material.[16]

Liquid resin was then poured into the lying-down body which drained into cavities and solidified there. In Ptolemaic times (332-30 BCE), pitch was also found mixed with the resin in mummies that were analyzed.[17]

Also, it is typical for many bone fragments to be found inside the body vaults and abdomens. Small bones break as the bodies are handled, and they scatter along the large body cavities.

The embalming ritual is described in two Papyri, probably copied from the same ancient source dating from the Greco-Roman period: *Papyrus Bulaq* 3 preserved in Cairo and *Papyrus* 5158 preserved at the Louvre. The Apis embalming ritual, the Vienna Papyrus *Vindobonensis* 3873 used for bull embalming, was also a reference for the priests' practices during mummification of humans.[18]

These ancient Egyptian sources stated that sacred texts were read out loud and rituals chanted while ingredients such as cinnamon, animal fat, and minerals were applied during the mummification process. Embalmers used incense oil, and the resin worked as glue to make the linen bandages stick well. According to ancient Egyptian beliefs, medicine and magic were a bundled concept and the chanting of rituals was necessary during the mummification process.

The role of the priests and their sacred blessings will not be described here in detail[19] except to add that the priests in charge of mummification procedures felt that what was missing in life could not be missing in the afterlife. Therefore, mummified bodies would have artificial body parts attached to them. These artifacts were created to make the bodies whole.

For example, bodies not identified according to their sex could have attached to them fake sexual organs (such as a female thought to be male), false eyes,[20] or prosthetics.[21] A toe may have been added if one were missing.[22] A toe was added to a mummy preserved at the British Museum (British Museum EA 29996). An incisive tooth may have been replaced,[23] or even an entire limb or hand.[24] An example of this is the 'prosthetic' forearm of the Darlington (Durham) mummy (no number); and the fake feet and penis on a mummy in the Manchester Museum (no. 1770).[25] Similarly, a foot prosthetic is displayed in the Cairo Museum (no number). Yet another example of such restoration was found in Mummy 2343 in the Naples Archaeological Museum, where an x-ray test showed

two wooden feet to be present. These types of restorations date back to the Ptolemaic Period.[26]

Modern Techniques for Analyzing Mummies

The ingredients that were applied by the ancient Egyptians allowed the bodies to be preserved sufficiently to enable modern-day studies. However, we cannot study mummies in detail without modern technologies. We can now scan human bodies and body parts[27] using non-invasive techniques.

Radiology was one of the biggest inventions to advance the medical observation of both living and deceased humans[28]. With the discovery of x-rays by Roentgen in 1895 and the subsequent development of radiology, a fundamental step was made in medical diagnosis possibilities. Since its invention, radiology has been used to study ancient human remains, including ancient Egyptian bodies.[29] We can learn about historical factors such as what happened at the time of death, the cause of death (*e.g.* blunt force trauma), and weapons used in case of violent death (*e.g.* axes, arrows, swords).[30]

We can also use endoscopy[31] and microscopy (histological analysis) to examine what is found inside a mummified body.

Contemporary computerized software allows scientists and historians to delve into the depths of a 3,000-year-old body either without destroying it or with minimal impact. We can learn how a person lived, suffered, and died – and what kinds of materials were used to preserve the body. Many forensic techniques can be used to examine human fragments. In addition to radiology and the other techniques noted above, these include histology, serology, ancient DNA (aDNA) identification,[32] osteology, as well as paleopathology techniques such as chemistry, isotope and carbon tests. A macroscopic examination should always be performed prior to any such laboratory tests.

Identification of DNA (deoxyribonucleic acid), developed in 1985, helps show family relationships and genetic correlation between individuals.[33] What we can learn from aDNA samples[34] about kinship and paleopathological conditions is limitless. In the aDNA of Egyptian mummies, even the pathogens can be studied,[35] as exemplified by a recent study directed by Zink *et al.*[36]

DNA retrieval methods were improved in 1991 with the application of Polymerase Chain Reaction (PCR) techniques, which allow

DNA to be cloned and produce multiple copies of specific sections of DNA. The long bones of a body tend to provide viable sample material, as they have more bone marrow which can be used for DNA testing. The genetic material -- sometimes presumed lost over time -- may still be viable and valid, and PCR techniques multiply the probability of getting positive results from tests on genetic material.

Some biomedical analysis techniques (*e.g.* computer tomography-CT scans[37] and traditional radiology[38]) have developed very rapidly in recent years. However, they only complement DNA tests.

Uses and Applications for Mummy Research

Through advanced forensic techniques we can learn about: ancient diet;[39] diseases;[40] causes of death (such as plagues infesting crops); climate changes[41] and famines (as shown in bone markers);[42] hemorrhagic fevers caused by bacteria; animals bites and stings; inflammation processes from trauma; genetic disorders, as shown in ancient DNA samples; hair lice; blindness caused by sand,[43] wind or stone quarrying; water worms in the Nile River;[44] and battles.

In general, we can say that many diseases afflicted ancient Egyptians,[45] mostly dental and pulmonary diseases, as their diet contained large amounts of sand. The excessive consumption of meat by high-ranking Egyptian officials may have provoked other diseases such as calcification of the aorta, arteriosclerosis,[46] atheroma,[47] fibrosis in muscle tissues, and aneurysms.

Bone diseases and trauma were also common in human remains from ancient Egypt, although researchers examining the royal mummies[48] concluded that inflammatory bone diseases were rarely seen in ancient Egyptian skeletons. Skeletal conditions included intra-vertebral disc disease and fractures.[49] Bones were subjected to stress from carrying heavy loads,[50] trauma inflicted in battle,[51] horseback riding, boating accidents, and sports. The most common result was osteoarthritis[52] and bone tumours,[53] although the number of occurrences was not high.[54] Nutritional stress and the lack of certain minerals[55] in the diet contributed to these osteological conditions in adolescents and young adults.

More recent tests[56] also show severe infectious diseases. These may have resulted from working in or near the Nile River and its effluents, channels, and ponds; fishing; and interacting with wild animals. Infections like schistosomiasis[57] and leishmaniasis[58] have been identified. Parasites, such as helmintic ova, were found in the PUM II mummy at the Royal

Ontario Museum[59] in Toronto. Other parasites,[60] such as pulmonary silicosis, pneumoconiosis,[61] and malaria[62] have also been found.

Dental diseases[63] were extensive,[64] including dental abrasions, caries, and periodontal disease.[65] Additional conditions that existed include diabetes and heart disease. There were many cases of Harris lines, which are growth-arrest lines.[66]

Various research projects[67] have focused on hair[68] in ancient Egyptian mummies. Researchers have reached astonishing conclusions about hairdressing and the ingredients in cones and unguents used for hair and wigs. Their results show that hair was treated separately from the body, sometimes with different mummification procedures and substances.[69]

As noted, it is common to find objects buried with human remains. Even in a non-funerary context, the excavation of plant remains can be crucial.[70] According to ancient texts, plants were used as medicine in ancient Egypt. This helps explain how ancient diseases may offer answers for contemporary ailments, thus pointing the way to the production of new medicines, perhaps with the help of genetic research.[71]

The study of DNA in ancient bodies is particularly relevant if the intent is to diagram a disease's evolution. An individual's digital genetic imprint is influenced by the genes of his or her relatives.[72] The genes can provide precise information about a family's inherited malignancies and genetic diseases. This is important since royal members in ancient Egypt tended to intermarry among themselves. There are two types of aDNA that can be retrieved from a specimen: mitochondrial DNA is inherited from the mother; nuclear DNA is inherited from both parents and is a more difficult sample to get.[73]

According to Dr. Angelique Corthals,[74] genotype defines phenotype (appearance). The application of DNA testing can help to determine, for instance, whether the strange physiognomy observed in pharaoh Akhenaten and his offspring, possibly including Tutankhamun, derives from a genetic "corridor" (genetically-inherited feature) set up by his ancestors.[75] During the New Kingdom period, the environment did not change substantially enough where this pharaoh and his family lived to disrupt the genetic trace, making it possible to confirm the differentiation of a genetic character in Akhenaten and subsequent passage to his offspring.

Mummy Storage and Museum Display

Mummies can be damaged through: improper display or storage; inadequate humidity level, air movement,[76] and light; and also by fungal spores and insects present in bodies and coffins.

Mummified human remains cannot be stored the same way as other museum artifacts.[77],[78] Humidity in the air and moisture inside the case must be controlled,[79] and dehumidifiers are considered essential, as mummy cases can decay almost as much as their contents, the bodies.

Further, the size of the display cases must be adequate to accommodate the human remains.[80] Being displayed in physically-correct positions – with minimum stress to joints – can ensure that a mummy is displayed without damage. Skulls and other bone fragments must be supported when they are loose from the body. Aluminum splints can be used in broken limbs. Re-bandaging, or re-wrapping, is another option. Paper or other base tissue must be replaced periodically. Foam beds, like the ones used for the Manchester Museum mummies, are also advisable. Mortuary-type trolleys can provide easy movement around museum displays and storage rooms.

Covering human remains has been an issue in some countries. An example of this is a Manchester Museum mummy named Asru who was displayed uncovered until 2008. Following the polemic debate in the United Kingdom, the mummy was covered in May 2008 and later uncovered again.[81]

Challenges in Studying Mummies

Several challenges arise in the study of mummies. One challenge relates to the availability of biomedical techniques. When appropriate techniques do exist, there is also the question as to whether the financial means are available to use those biomedical techniques. There is also the question as to whether the necessary administrative permissions (from museums and other authorities) are in place to allow scientists and historians to do sampling tests.

A factor influencing mummy preservation and museum display is the state in which the mummy is found. Some mummies are very well preserved. In others, contamination may prevent scientists from getting positive results. The majority of disturbances and attacks destroying mummified bodies and skeletons take place post-mortem (after death).

In ancient Egypt, mummies were reburied, misplaced, unidentified, transferred, and housed in different sarcophagi. In antiquity, disruptions occurred mainly due to robbers' activities, political changes, and natural elements that caused the loss of body identification. When moved from Egypt, they were also handled by many people, most not knowing they were handling human remains, or not paying the attention needed.

Most of the findings in archaeological contexts involve bodies that are already disarticulated[82] and groups of bones that are not placed in their original anatomical position. It is common for bones to be missing. Fingers and toes, for instance, are small and easily disarticulated. They get lost on the ground, or in the coffin, and many times they are lost while handling the mummy. When coffins were used that did not fit the size of the mummy,[83] the feet and skulls were often broken.

Once these issues are resolved, analysis of a mummy is not unlike that of a modern day autopsy.

Between the layers of linen wrappings, we may also find amulets,[84] insects, solidified resin, and fungi. The original mummification procedures and ritual chanting allowed time for flies to lay eggs, a factor altering the mummification, and creating disturbing conditions as the body desiccated. Another cause for mold or fungi[85] found in mummies may be re-used linen,[86] as not all ancient Egyptians had the financial means to ensure a "pure" mummification without recycled materials. Some mummies are completely "naked," as illustrated by a female specimen in an Egyptian collection housed at the Faculty of Sciences in Porto, Portugal.[87]

Pollen[88] is also found in mummies, due to the fact that the plants used for oils (used in mummification) carry pollen. This pollen can alter the skin tone sometimes causing the appearance of dark spots. Pollen also appears in coprolites (fossilized feces).

In the absence of contamination, it is possible to sequence DNA.[89] Various types of mummification techniques can impair aDNA retrieval.[90] Some ingredients used during mummification (oils, resins) degrade the tissue to such an extent that aDNA retrieval is almost impossible. As the samples degrade over time, their chemical substances impair any conclusive results. The important issue before taking a sample from a mummy is to try to determinate what materials were used during the mummification process. Alkaloids commonly found in bandages and bodies only reveal some substances, and others are common to various

plants and resins used. Therefore, we cannot confirm with total certainty which ones were used in each case.[91]

In terms of DNA extraction, some authors[92] have raised doubts about the conservation of DNA over long periods of time. Studies[93] have been conducted on Egyptian tissue material in order to produce more convincing data. Researchers are attempting to refine information in order to determine when the last DNA molecules vanished. Present results indicate that the preservation limit for archaeological DNA in Egypt is less than 1,000 years. The high temperature levels in the Egyptian environment seem to be the prevailing cause of DNA degradation.[94]

Mummified human remains from ancient Egypt have reached our present time in excellent conditions. There are some extraordinary examples still waiting for complete scanning and DNA tests. These include the "Tutankhamun's fetuses" (1336-1327 BCE) – two girls thought to be sisters (maybe twins, as suggested by Connolly),[95] and who have different body shapes. He believes their differences are symptoms of a rare event in which one twin consumed more nutrients from the mother than the other twin, and was therefore born much bigger and stronger.[96] Premature or severely ill newborn babies rarely survived in antiquity, and often a child died in the mother's womb. It is probable that Tutankhamun's daughters are an example of this, as they were far from full-grown babies who died at five and six month's gestation.

Conclusions

What we can learn from studying human remains is important for both history and science. The study of mummified material allows us to search for diseases that existed in ancient Egypt. The medical, biographical, phenotypal data and accessory information that can be retrieved from mummies on a macroscopic or molecular level is important. Researchers studying mummies must perform detailed analyses of not only the bodies, but also the items surrounding the bodies – including bandages, amulets, prosthetics, false body parts, plants, insects, dyes, and inscriptions. The detailed study of these materials may provide researchers clues about ancient civilization and their scientific and technical knowledge and concerns. Religion and magic were science then. This reminds me of Clarke's third law: "*Any sufficiently advanced technology is indistinguishable from magic.*"

Modern non-invasive techniques for analysis provide ample information without destroying the surrounding artifacts. DNA

identification is a powerful instrument, although there are disagreements among scientists about the limitations of DNA preservation. However, the most helpful findings and conclusions are drawn from specific tests that require samples which are destroyed in the process. An example: Tests on a tooth's root which requires smashing it, but which can be decisive to prove age at the time of death. For such analyses, special permissions from the museums and institutions housing the mummies are of the essence. Not all museum authorities are sensitive to the urgency of taking samples from human remains.

Ancient human remains come from times when pollution from industry and vehicles, tobacco, genetically-modified foods, chemical drugs, stress, and trauma caused by machines did not exist. This may be relevant from the pharmaceutical point of view. The cores of active substances in our modern medicines are chemical copies of their vegetable counterparts. Those same vegetable substances used with confirmed results by ancient people may point the direction to find better medicines for today.

Bureaucracy and the fear of damaging artifacts should not impede scientific tests that might result in scientific progress today. Contemporary technologies used to diagnose and cure the living should also be made available to address the dead in order to bring history and facts into closer alignment. The texts that survived from ancient Egypt – medical, magical, personal letters, religious or simply funerary – contain information that can be compared with the findings from human remains to confirm treatments and prophylaxis and identify ingredients used.

This information can enlighten our understanding of ancient medicine when brought together in multidisciplinary research projects involving specialists from different fields such as medicine, botany, linguistics, history and imaging. It could change history.

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Bibliography

Antoine, D., (2010), The Department of Ancient Egypt and Sudan at the British Museum, *Ancient Egypt Magazine*, Manchester Empire Publications: 46-51.

Aufderheide, A. C., (1998), *The Cambridge Encyclopedia of Human Paleopathology*, Cambridge University Press.

Aufderheide, A. C., (2003), *The Scientific Study of Mummies*, Cambridge, Cambridge University Press.

Bauduer, F., (2005), Diseases and Therapies in Ancient Egypt: What Mummies and Other Human Remains Tell Us? *in* Massa, E. R. (Ed.), *Proceedings of the V World Congress on Mummy Studies*, Torino, Compagnia di San Paolo: 69-72.

Bernhardt, C. E., Horton, B. P., Stanley, J. D., (2012), Nile Delta Vegetation Response to Holocene Climate Variability, *Geology*, 40, 7: 615-618.

Brancaglion, Jr., A., De Souza, S., (2005), The Egyptian Collection of Museu Nacional, Rio de Janeiro, Brazil, and the Conservation of Mummies in a Tropical Environment *in* Massa, E. R. (Ed.), *Proceedings of the V World Mummy Congress*, Torino, Compagnia di San Paolo: 129-131.

Cesarani, F., Martina, M. C., Ferraris, A., Grilletto, R., Boano, R., Marochetti, E. F., Donadoni, A. M., Gandini, G., (2003), Whole-Body Three-Dimensional Multidetector CT of 13 Egyptian Human Mummies, *American Journal Roentgenology*, 180: 597-606.

Cesarani, F., Martina, M. C., Ferraris, A., Grilletto, R., Boano, R., Colombini, M. P., Modugno, F., Silvano, F., Onor, M., (2000) Characterization of the Balm of an Egyptian Mummy from the Seventh Century B.C., *Studies in Conservation*, 45: 19-29.

Cockburn, A., Barraco, R. A., Reyman, T. A., Peck, W. H., (1975), Autopsy of an Egyptian Mummy, *Science*, 187: 1155-1160.

Cockburn, A., Cockburn, E., Reyman, T. A., (1980), *Mummies, Disease & Ancient Cultures*, Cambridge, Cambridge University Press.

Cosmacini, P., Piacentini, P., (June 2011), Egyptian Mummies and Radiology: A Closer Link *in* Zink, A., Rosendahl, W., Gill-Frerking, H. (Eds.), *Yearbook of Mummy Studies 1*, München, Verlag Dr. Friedrich Pfeil: 37-44.

Counsell, D. J., (2006), *Intoxicants in Ancient Egypt: The Application of Modern Forensic Analytical Techniques to Ancient Artifacts and Mummified Remains in the Evaluation of Drug Use by an Ancient Society; A Historical and Scientific Investigation*, Thesis submitted to the University of Manchester.

Counsell, D. J., (October-November 2008), Tutankhamun's Murder: Case Reopened? *Ancient Egypt Magazine*, 9: 34-40.

David, R., Tapp, E., (1993), *The Mummy's Tale, The Scientific and Medical Investigation of Natsef-Amun, Priest in the Temple at Karnak*, New York, St. Martin's Press.

David, R., David, A., (1995), Preservation of Human Mummified Specimens in Collins, Chris (ed.), *Care and Conservation of Paleontological Material*, Oxford, Butterworth: 73-88.

David, R., (2000), 5000 Years of Schistosomiasis in Egypt, *Chungara Revista de Antropologia Chilena*, 32, 1: 133-135.

David, R., (2001), The Tomb of Two Brothers at Rifeh, Egypt: Paleopathological and Archaeological Studies *in* Lynnerup, N. (Ed.), *Proceedings of the IV World Mummy Congress*, Greenland, Greenland National Museum and Archives and Danish Polar Centre: 169-173.

David, R., (2001), Benefits and Disadvantages of Some Conservation Treatments for Egyptian Mummies, *Chungara Revista de Antropología Chilena*, 33, 1: 113-115.

David, R., (2005), Natsef-Amun, Keeper of the Bulls, A Comparative Study of the Palaeopathology and Archaeology of an Egyptian Mummy, *in* Massa, E. R. (Ed.), *Proceedings of the V World Mummy Congress*, Torino, Compagnia di San Paolo: 175-178.

David, R., (2007), *The Two Brothers: Death and the Afterlife in Middle Kingdom Egypt*, Exeter, U.K., Rutherford Press Limited.

David, R., (2008), *Egyptian Mummies* and Modern *Science,* Cambridge University Press.

David, R. A., Kershaw, A., Heagerty, A., (2010), Atherosclerosis and Diet in Ancient Egypt, *The Lancet* - 27 February 2010, 375, 9716: 718-719.

Davies, E., (2011), Mummified Remains from Egypt and Beyond Hold Chemical Information about the Daily Lives of Ancient Civilisations, *Chemistry World*: 48-51.

De Souza, S., (2005), The Egyptian Mummy Hori: A Conservation Assessment of Brazil's Museum Nacional's Egyptian Mummy Hori for Exhibition *in* Massa, E. R. (Ed.), *V World Mummy Congress*, Torino, Compagnia di San Paolo: 132-135.

Donoghue, H., et al, (2010), Tuberculosis in Dr. Granville's mummy: A Molecular Re-examination of the Earliest Known Egyptian Mummy to be Scientifically Examined and Given a Medical Diagnosis, *Proceedings of the Royal Society Biological Sciences,* 7, 277, 1678: 51-56.

Ebeid, N. I., (1999), *Egyptian Medicine in the Days of the Pharaohs*, Cairo, General Egyptian Book Organization.

Filce Leek, F., (1972), Bite, Attrition and Associated Oral Conditions as Seen in Ancient Egyptian Skulls, *Journal of Human Evolution*, 1: 289-295.

Fornaciari, G., Giuffra, V., (2005), Paleopathological Study of the Egyptian Mummies Collected in Italy: The Anubis Project *in* Massa, E. R. (Ed.), *Proceedings of the V World Mummy Congress,* Torino, Compagnia di San Paolo: 255-257.

Fornaciari, G., Giuffra, V., Ciranni, R., (2006), A New Case of Ancient Restoration on an Egyptian Mummy, *The Journal of Egyptian Archaeology*, 92: 274-278.

Forshaw, R., Corthals, A., (June 2011), Multidisciplinary Investigation of the Manchester Elliot Smith Skulls *in* Zink, A., Rosendahl, W., Gill-Frerking, H., *Yearbook of Mummy Studies 1*, München, Verlag Dr. Friedrich Pfeil: 57-62.

Forshaw, R., (June-July 2009), Dental Health and Dentistry in Ancient Egypt, *Ancient Egypt Magazine*, 9: 24-28.

Fulcheri, E., Boano, R., Grilletto, R., Ferrari, L., Leospo. E., Donnadoni Roveri, A. M., Rabino Massa, E., (2001), Ancient Egyptian Mummies: Histological Examinations to Assess the Presence of Contaminants or Pollutants *in* Lynnerup, N. (Ed.), *Proceedings of the IV World Mummy Congress*, Greenland, Greenland National Museum and Archives and Danish Polar Centre: 89-91.

Galán, J. M., (Autumn 2009), An Intact Eleventh Dynasty Burial in Dra Abu el-Naga, *Egyptian Archaeology*: 32-35.

Gray, P. H. K., (December 1966), Embalmers' 'Restorations,' *The Journal of Egyptian Archaeology*, 52: 138-140.

Gray, P. H. K., (1967), Radiography of Ancient Egyptian Mummies, *Medical Radiography and Photography*, 43: 34-44.

Gray, P. H. K., (1971), Artificial Eyes in Mummies, *The Journal of Egyptian Archaeology*, 57: 125-126.

Harer, W. B., (September-October 2007), Chariots, Horses or Hippos: What Killed Tutankhamun? *Minerva*, 18: 8-10.

Hawass, Z., (October-November 2007), Meeting Tutankhamun, *Ancient Egypt Magazine*, 8: 29-36.

Horne, P., (2001), Disease in Mummies from Two Sites in Ancient Egypt *in* Lynnerup, N. (Ed.), *Proceedings of the IV World Mummy Congress*, Greenland, Greenland National Museum and Archives and Danish Polar Centre: 111-112.

Irish, J. D., (2004), A 5,500-Year Old Artificial Human Tooth From Egypt: A Historical Note, *The International Journal of Oral & Maxillofacial Implants*, 19: 645-647.

Janot, F., (2005), The Mummies of Kha and Merit: Embalming Ritual and Restoration Work *in* Massa, E. R. (Ed.), *Proceedings of the V World Mummy Congress*, Torino, Compagnia di San Paolo: 243-247.

Kemp, B., (2010), Tell el-Amarna, 2010, *The Journal of Egyptian Archaeology* 96: 1-29.

Kloos, H., David, R., (2002), The Paleoepidemiology of Schistosomiasis in Ancient Egypt, Research in Human Ecology, *Human Ecology Review*, 9: 14-25.

Lambert-Zazulak, P., Rutherford, P., David, R., (2003), The International Ancient Egyptian Mummy Tissue Bank at the Manchester Museum as a Resource for the Palaeoepidemiological Study of Schistosomiasis, *World Archaeology*, 35, 2, Archaeology of Epidemic and Infectious Disease (Oct. 2003): 223-240.

Lucas, A., (1914), The Question of the Use of Bitumen or Pitch by the Ancient Egyptians in Mummification, *The Journal of Egyptian Archaeology*1, 4, Oct., 1914: 241-245.

Maes, F., (January-February 2005), Egyptian Mummies at the National Museum of Antiquities, Leiden, *Minerva*, 16: 8-12.

Marota, I., Basile, C., Ubaldi, M., Rollo, F., (2002), DNA Decay Rate in Papyri and Human Remains from Egyptian Archaeological Sites, *American Journal of Physical Anthropology*, 117, 4: 310-318.

McCreesh, N. C., Gize, A. P., Denton, J., David, R., (June 2011), Hair Analysis: A Tool for Identifying Pathological and Social Information *in* Zink, A., Rosendahl, W., Gill-Frerking, H., *Yearbook of Mummy Studies 1*, München, Verlag Dr. Friedrich Pfeil: 95-98.

McCreesh, N., C., Gize, A., P., David, A., R., (December 2011), Ancient Egyptian Hair Gel: New Insight into Ancient Egyptian Mummification Procedures through Chemical Analysis, *Journal of Archaeological Science*, 38, 12: 3432-3434.

Micozzi, M. S., (1992), Post-Mortem Preservation of Human Remains: Natural and Technical Processes, *Proceedings of the I World Mummy Congress,* Tenerife, Museo Arqueologico y Etnografico de Tenerife: 759-764.

Minnikin, D. E., Besra, G. S., Lee, Oona Y-C, Spiegelman, M., Donoghue, H. D., (June 2011),The Interplay of DNA and Lipid Biomarkers in the Detection of Tuberculosis and Leprosy in Mummies and Other Skeletal Remains, *in* Zink, A., Rosendahl, W., Gill-Frerking, H., (Eds.) *Yearbook of Mummy Studies 1*, München, Verlag Dr. Friedrich Pfeil: 109-114.

Morimoto, I., (1985), *Series of Studies in Egyptian Culture, 2, The Human Mummies from the 1983 Excavations at Qurna, Egypt*, Institute of Archaeology, Waseda University, Tokyo.

Murray, M. A., (1910), *The Tomb of Two Brothers*, Manchester, Sherratt & Hughes.

Nelson, A. J., Chhem, R., Cunningham, I. A., Friedman, S. N., Garvin, G., Gibson, G., Granton, P. V., Holdsworth, D. W., Holowka, S., Longstaffe, F., Lywood, V., Nguyen, N., Shaw, R., Trumpour, M., Wade, A. D., White, C., D., (June 2011), The ROM/UWO Mummy Project: A Microcosm of Progress in Mummy Research, *in* Zink, A., Rosendahl, W., Gill-Frerking, H., (Eds.) *Yearbook of Mummy Studies 1*, München, Verlag Dr. Friedrich Pfeil: 127-132.

Nerlich, A. G., Haas, C. J., Zink, A., Szeimies, U., Hagedorn, H. G., (1997), Molecular Evidence for Tuberculosis in an Ancient Egyptian Mummy, *The Lancet*, 350, 9088: 1404.

Paabo, S. (1985), Molecular Cloning of Ancient Egyptian Mummy DNA, *Nature*, 314, 6012: 644-645.

Paabo, S., (1989), Ancient DNA: Extraction, Characterization, Molecular Cloning, and Enzymatic Amplification, *Proceedings National Academy of Sciences*, USA, 86, Genetics: 1939-1943.

Pahor, A., (1992) Ear, Nose and Throat in Ancient Egypt, *The Journal of Laryngology and Otology*, 106: 773-779.

Parsche, F., (1992), A Contribution to the Problem of Beetle Attacks in Egyptian Mummies, *Proceedings of the I World Mummy Congress,* Tenerife, Museo Arqueológico y Etnográfico de Tenerife: 877.

Pettigrew, T. J., (1838), *Account of the Examination of the Mummy of Pet-maut-ioh-mes*, London, J. B. Nichols & Son.

Pope, F., (1992), After the Autopsy: The Continuing Conservation, Research and Interpretation of an Egyptian Mummy, Nakht ROM 1, *Proceedings of the I World Mummy Congress*, Tenerife, Museo Arqueológico y Etnográfico de Tenerife: 231-235.

Prates, C., Sousa, S., Oliveira, C., Ikram, S., (2011), Prostate Metastatic Bone Cancer in an Egyptian Ptolemaic Mummy, A Proposed Radiological Diagnosis, *International Journal of Paleopathology*, 1, 2: 98-103.

Rabino Massa, E., Boano, R., Meaglia, D., Dutto, G., Costa, E., (June 2011), The Biological Archive of the Museum of Anthropology and Ethnography of Turin: Microscopic Analysis to Assess the Preservation of Ancient Human Hair *in* Zink, A., Rosendahl, W., Gill-Frerking, H., (Eds.) *Yearbook of Mummy Studies 1*, München, Verlag Dr. Friedrich Pfeil: 29-32.

Rabino Massa, E., (2005), Detection of Plasmodium Falciparum Ancient DNA in Egyptian Mummies *in* Massa, E. R. (Ed.), *Proceedings of the V World Mummy Congress*, Torino: 88-90.

Ruffer, M. A., (1921), *Studies in the Palaeopathology of Egypt*, Chicago, University of Chicago Press.

Rutherford, P., (2000), The Diagnosis of Schistosomiasis in Modern and Ancient Tissues by Means of Immunocytochemistry, *Chungara Revista de Antropología Chilena*, 32, 1: 127-131.

Rutherford, P., (2005), Schistosomiasis in Modern and Ancient Tissues *in* Massa, E. R. (Ed.), *Proceedings of the V World Mummy Congress*, Torino, Compagnia di San Paolo: 80-83.

Samuel, D. W., (1997), Cereal Foods and Nutrition in Ancient Egypt, *Nutrition*, 13: 579-580.

Sandison, A. T., (1963), The Use of Natron in Mummification in Ancient Egypt, *Journal of Near Eastern Studies*, 22: 259-267.

Smith, G. E., (1914), Egyptian Mummies, *The Journal of Egyptian Archaeology*, 1: 189-196.

Spigelman, M. (2005), Preliminary Findings on the Paleomicrobiological Study of 400 Naturally Mummified Human Remains from Upper Nubia *in* Massa, E. R. (Ed.), *Proceedings of the V World Mummy Congress*, Torino, Compagnia di San Paolo: 91-95.

SCA, Supreme Council of Antiquities, (June-July 2005), The Mummy of Tutankhamun: The CT Scan Report, *Ancient Egypt Magazine*, 5: 34-37.

Schultz, M., (1992), The First Evidence of Microfilariasis in an old Egyptian Mummy, *Proceedings of the I World Mummy Congress,* Tenerife, Museo Arqueológico y Etnográfico de Tenerife: 317-320.

Strouhal, E., Thurzo, M., Hudec, J., Sefcakova, A., (2005), A New Egyptian Human Mummified Head in the Slovak National Museum, Bratislava, *The Journal of Egyptian Archaeology*, 91: 190-197.

Strouhal, E., (2005), Examination of Mummies from the Tomb of Iufaa at Abusir (Egypt) *in* Massa, E. R. (Ed.), *Proceedings of the V World Congress on Mummy Studies*, Torino, Compagnia di San Paolo: 179-183.

Taher, A. W., (October-November 2007), The Mummy of Queen Hatshepsut Identified, *Ancient Egypt Magazine*, 8: 10-13.

Van Tiggelen, R., (2004), Ancient Egypt and Radiology, A Future for the Past! *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, 226: 10-14.

Vass, A., (November 2001), Beyond the Grave – Understanding Human Decomposition, *Microbiology Today,* Spencers Wood Society for General Microbiology, 28: 190–192.

Veiga, P. (2012), Some Prevalent Pathologies in Ancient Egypt, *Hathor – Studies of Egyptology I*, Instituto Oriental, Faculdade de Ciências Sociais e Humanas da Universidade Nova de Lisboa, pp. 63-83.

Veiga, P. A., (2009), *Oncology and Infectious Diseases in Ancient Egypt: The Ebers Papyrus? Treatise on Tumours 857-877 and the Cases Found in Ancient Egyptian Human Material*, Saarbrücken, VDM Verlag.

Veiga, P. A., (2009b), *Health and Medicine in Ancient Egypt; Magic and Science*, (2009), BAR (British Archaeological Reports) Archaeopress. Oxford.

Ventura, L., Mercurio, C., Guidotti, C., Fornaciari, G., (2005), Tissue Identification and Histologic Findings in Four Specimens from Egyptian Canopic Jars, *Journal of Biological Research*, LXXX, 1, *Proceedings of the V World Congress on Mummy Studies*, Pisa.

Waldron, T., (1992), Some Mummies from Theban Tombs 253, 254 and 294, *Proceedings of the I World Mummy Congress*, Tenerife, Museo Arqueológico y Etnográfico de Tenerife: 847-852.

Wayne, R. K., Leonard, J. A., Cooper, A., (1999), Full of Sound and Fury: History of Ancient DNA, *Annual Review of Ecology and Systematics*, 30: 457-477.

Zink, A., Reischl, U., Wolf, H., Nerlich, A. G., (2000), Molecular Evidence of Bacteremia by Gastrointestinal Pathogenic Bacteria in an Infant Mummy from Ancient Egypt, *Archives of Pathology & Laboratory Medicine*, 124, 11: 1614-1618.

Zink, A., et al, (2003), Characterization of *Mycobacterium Tuberculosis* Complex DNAs from Egyptian Mummies by Spoligotyping, *Journal of Clinical Microbiology*, 359–367.

Zink, A., (2010), Der DNA-Detektiv, Der Fall Tutanchamun, *National Geographic Deutschland*, Hamburg: 30-61.

Online Resources

Microbial Growth in Pharaoh's Tomb Suggests Burial Was a Rush Job: http://www.eurekalert.org/pub_releases/2011-06/hu-ttm060811.php [accessed July 20, 2011]

Mummies, Smithsonian Magazine: http://www.smithsonianmag.com/history-archaeology/Fascinating_Relics.html [accessed July 15, 2011]

Tutankhamun Foetuses: http://www.dailymail.co.uk/sciencetech/article-1051230/Foetuses-King-Tutankhamuns-tomb-twin-daughters-says-expert.html [accessed July 10, 2011]

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[1] In Latin, to lie down in aromatic resins, one of the last stages of mummification procedures; Ebeid, (1999):422.
[2] David and Tapp, (1993): 37; Cosmacini et al., (2011): 37.
[3] Vass, (2001): 190-192.
[4] Aufderheide, 2003: 44.
[5] David, (1995): 77.
[6] David, (1995): 78; Parsche, (1992): 877.
[7] David, 1995: 73.
[8] Such as the examples kept at the British Museum, excavated from Gebelein, Egypt; the most famous which is on display being 'Ginger', EA 32751; Micozzi, (1992): 760; Gray, (1967): 34; Aufderheide, (2003): 220; Cesarani et al, (2003): 597.
[9] As depicted by 'Ginger' in the British Museum.
[10] My personal work in collaboration with the team studying the human remains from TT37, under the supervision of Dr. Tiradritti, has enriched my knowledge of how the Egyptian climate can preserve human remains.
[11] Murray, (1910), *The Tomb of Two Brothers*, Manchester, Sherratt & Hughes; David, (2007), *The Two Brothers: Death and the Afterlife in Middle Kingdom Egypt*, Exeter, U.K., Rutherford Press Limited.
[12] Cosmacini et al., (2011): 37.
[13] Veiga, (2009b): 20.
[14] Gray, (1967): 36.
[15] Sodium carbonate, sodium bicarbonate, impurities as salts of iron, calcium and silicon; Gray, (1967) 34-44: 35.
[16] Sandison, (1963): 259-267.
[17] Lucas, (1914): 32.

[18] "(...) The Embalming Ritual is described in two Papyri, probably copied from the same ancient source, dating from the Greco-Roman period, and housed in Cairo: Papyrus Bulaq 3, and at the Louvre, Papyrus 5158. In this last one, the embalming is said to begin only four days after death, the linen bandaging 46 days after, so 42 days are left for the rituals. They used incense oil and the used resin worked as glue so it should be sticky to make the linen bandages stick well. (...) from Veiga, (2009): 22.

[19] Veiga, (2009b).

[20] Van Tiggelen, (2004): 10-14; Gray, (1971): 125-126; Gray, (1967): 36.

[21] Bauduer, (2005): 69-72; Fornaciari et al, (2006): 274-278.

[22] British Museum: EA 29996; Gray, 1966: 138-9, Plates XXXII, XXXIII, XXXIV. The work of my colleague Dr. Jacky Finch, from Manchester has developed around prosthetic medicine in ancient Egypt.

[23] Irish, (2004): 645.

[24] Gray, (1966): 138 and Plate XXXIII.

[25] As Dr. Jacky Finch, who is conducting the research on prosthetics in ancient Egypt was my colleague and is a personal friend. I have followed her research, but there are some scientific publications on that, available at: New Light on Ancient Egyptian Prosthetic Medicine: http://www.nicholasreeves.com/item.aspx?category=Writing&id=75; World's First Prosthetic: Egyptian Mummy's Fake Toe: http://www.livescience.com/4555-world-prosthetic-egyptian-mummy-fake-toe.html; The ancient origins of prosthetic medicine: http://www.thelancet.com/journals/lancet/article/PIIS0140-6736%2811%2960190-6/fulltext

[26] Fornaciari *et al.*, (2006): 274-278.

[27] Strouhal *et al*, (2005): 190-191.

[28] Cosmacini *et al.*, (2011): 37-44.

[29] Cosmacini *et al.*, (2011): 38.

[30] Waldron, (1992): 847-852; King Seqenenre Tao suffered an injury to his nose resulting in fracture of both nasal bones and destruction of the supra-orbital margin, inflicted by a blunt instrument such as a stick or an axe; Pahor, (1992): 775.

[31] Fornaciari et al, (2005): 255-257; Lambert-Zazulak *et al*, (2003): 223-240.

[32] I owe my specific knowledge in this field to Dr. Angelique Corthals, now in New York, previously at the KNH Center, Manchester, U.K..; Lambert-Zazulak, (2003): 223-240.

[33] When studying the biomedical techniques for Egyptology at Manchester, U.K., I learned about aDNA retrieval and experienced lab work on it.

[34] First published by Paabo, (1985): 644-645.

[35] Zink, (2003): 359.

[36] Published in paper version of National Geographic Deutschland, Zink, A., (2010), Der Dna-Detektiv, Der Fall Tutanchamun, *National Geographic Deutschland*, Hamburg: 30-61.

[37] SCA, (June July 2005): 34-37; Taher, (October November 2007): 10-13; Hawass, (October November 2007): 29-36; Harer, (September October 2007): 8-10; MAES, F. (January February 2005): 8-12; Nelson, (2011): 129.

[38] Too many studies have been conducted so far, in Europe and North America, to mention here. As other references in this article, there are already many cases studied and, if interested, the reader can contact the author for further bibliographic material: veigapau@gmail.com

[39] David *et al.*, 2010: 718-719.
[40] Prates *et al*, 2011: 98-103.
[41] Bernhardt *et al*, 2012: 615-618.
[42] Dental hypoplasia and Harris lines on long bones.
[43] Presence of pulmonary silicoanthracosis confirmation in Ventura et al, (2005): 355-356.
[44] Kloos, David, (2002): 14-22.
[45] Veiga, (2009b), chapter 3; Veiga, 2012:63-83.
[46] Bauduer, (2005): 69-72; David, (2005): 175-178.
[47] David, (2005): 175-178.
[48] Smith, (1914): 189-196.
[49] Gray, (1967): 41; Counsell, (October November 2008): 41.
[50] Dr. Jerome Rose has found many cases among the individuals found at the Amarna site; Kemp, (2010): 29.
[51] Bauduer, (2005): 69-72; Galán, (Autumn 2009): 32-35.
[52] David, (2002): 169-173; Gray, (1967): 41.
[53] Strouhal, (2005): 179-183; Fornaciari et al, (2005): 255-257.
[54] Bauduer, (2005): 69-72; Veiga, (2009): 21, 34, 82, 83, 84, 91, 113.
[55] Spigelman, (2005): 91-95.
[56] Cockburn et al., (1980): 59-67.
[57] Horne, (2001): 111-112; David, (2002): 169-173; Bauduer, (2005): 69-72; Rutherford, (2005): 80-83; Kloos et al, (2002): 14-25; Rutherford, (2000): 127-131; David, (2000): 133-135; Kloos et al, (2002): 14-25; Lambert-Zazulak et al (2003): 223-240.
[58] Spigelman, (2005): 91-95.
[59] Cockburn et al (1975): 1155-1160.
[60] Schultz, (1992): 317-320.
[61] David, (2002): 169-173.; Bauduer, (2005): 69-72.
[62] Ibid.
[63] Forshaw, Corthals, (2011): 61.
[64] I owe my knowledge in this specific field to Dr. Roger Forshaw, Honorary Research Associate in Dental Studies at the KNH Center, Manchester, U.K., who helped me with the literature and the examples, as he was a dentist before specializing in medicine in ancient Egypt; Samuel, (1997): 579-580; Filce Leek, (1972): 289-295; Forshaw, (June July 2009): 24-28.
[65] Bauduer, (2005): 69-72; Gray, (1967): 43.
[66] Gray, (1967): 41.
[67] Rabino Massa, (2011): 29-32; McCreesh, (2011): 95-98.
[68] Examples of ancient Egyptian hair exist in several museums, the British Museum being one of those; as proven by BM 54059, BM 6729, BM 22004, BM 6727, BM 6722, BM 6719.
[69] Davies, (2011): 48-51; Personal communications from Dr. McCreesh, October 2007-September 2008, and also on her published work: McCreesh, 2011: 3432-3434.
[70] I am presently working on this subject for my PhD.
[71] The way ancient civilizations dealt with their afflictions and their disturbances of natural order and health might inform the research of today's pharmacological substances, which are chemically altered from plants' natural active substances. Except for some unidentified and extinct plants, the majority of the flora found in ancient

times still exists, and has the potential to be applied to modern medicine, thus permitting a closer encounter between science and history.

[72] David, (2001): 169-173.

[73] Prof. Eugénia Cunha in a seminar of Forensic Anthropology, at the Lisboa Forensic Institute, February 2007.

[74] Dr. Angelique Corthals, CUNY John Jay College of Criminal Justice, Department of Sciences, N.Y., U.S.A.

[75] Zink, (2010): 30-61.

[76] Brancaglion, J. R., et al, (2005): 129-131; De Souza, (2005): 132-135.

[77] Antoine, (2010): 46-51.

[78] David, (1995): 80-86; David, (2001): 243-247.

[79] Pope, (1992): 231-235.

[80] Ibid.

[81] The great mummy cover-up: http://www.guardian.co.uk/artanddesign/artblog/2008/may/23/maevkennedyfriampic; 'Uncover the mummies': http://www.bbc.co.uk/manchester/content/articles/2008/05/22/220508_mummies_egypt_feature.shtml; Museums avoid displaying human remains 'out of respect': http://www.guardian.co.uk/culture/2010/oct/25/museums-human-remains-display

[82] Morimoto, I., (1983): 1.

[83] Janot, (2005): 243-247; Gray, 1966: 138.

[84] Gray, (1967): 41.

[85] Fulcheri et al, (2001): 89-91; Strouhal, (2005): 180; Janot, (2005): 243-247.

[86] Ibid.

[87] Preliminary report published by the author at: *How to Look Ten Years Older: Photos From the Scanning of a Mummy in Porto*, http://heritage-key.com/blogs/veigapaula/how-look-ten-years-older-photos-scanning-mummy-porto

[88] Spigelman, (2005): 93.

[89] Wayne et al, (1999): 457-477.

[90] Paabo, (1989): 1939.

[91] Counsell, (2006): 112-116; Colombini et al, (2000): 19-29.

[92] David, 2001: 113-115.

[93] Paabo, 1985; Paabo, 1989; Nerlich et al, 1997; Zink et al, 2000; Zink et al, 2003; Marota et al, 2002; David, 2008; Donoghue et al, 2010; Aufderheide, 1998; Aufderheide, 2003, and so many others.

[94] Marota et al, (2002): 310-318.

[95] As I have learned this directly from Dr. Connolly, and saw the x-rays at Manchester taken by him and his team, I can point here to several scholarly sources for the subject; Harrison et al, (1979), A Mummified Foetus from the Tomb of Tutankhamun, *Antiquity*, 53, 207: 19-21;A Re-assessment of the Larger Fetus Found in Tutankhamen's Tomb, Une Nouvelle Etude du Plus Grand des Foetus Trouvés dans la Tombe de Toutankhamon, (2009), *Antiquity*, 83, 319: 165-173. More recently a new article may provide additional information; Hawass, Z., Saleem, S. N., (2011), Mummified Daughters of King Tutankhamun: Archeologic and CT Studies, *American Journal of Roentgenology*, 197, 5, W829-W836.

[96] Dr. Connolly explained this theory to me himself, at Manchester's KNH Centre for Biomedical Egyptology in 2008.

Perspectives on Student Problem Solving and 21st Century Skills Developed at the Precollege Level

Bruce Furino

College of Engineering and Computer Science
University of Central Florida, Orlando, FL

Abstract

Changing young students' perceptions and attitudes towards engineering as a profession is an intended outcome of engineering outreach programs administered by colleges of engineering, professional engineering societies and a host of other organizations involved in science, technology, engineering and mathematics (STEM) education. The University of Central Florida through its College of Engineering and Computer Science's Outreach Office has for 15 years administered the Internet Science and Technology Fair (ISTF) to inspire students to consider engineering and other STEM careers and better understand the innovation process. It incorporates both problem solving and the development of 21st century learning skills through the use of problem-based learning. This article provides an analysis based on 2011-2012 ISTF program data regarding the student teams' research focus, feedback from their Final Process Evaluation and team assessments (via their final research projects) that addressed thinking skills developed by the students.

Introduction

PROBLEM SOLVING is one of the most popular terms used to describe what engineers do while applying principles of science and mathematics to solve technical problems. Too often, the technical requirements of the process obscure most laypersons from seeing or much less understanding its significance or contributions regarding the profession. Chuck Vest, President of the National Academy of Engineering (NAE), best conveyed this sentiment at the NAE Changing the Conversation website where he said, "Our economy, national security, and quality of life depend on engineers, so it is disturbing to see how few Americans, particularly young people, understand the importance and excitement of engineering." [1]

Changing young students' perceptions and attitudes towards engineering as a profession is an intended outcome of engineering outreach programs administered by colleges of engineering, professional engineering societies and a host of other organizations involved in science, technology, engineering and mathematics (STEM) education. Measuring

their effectiveness continues to be a challenge whether the programs are formally integrated into the precollege classroom or offered as an informal activity. In 2009, NAE published the report “Engineering in K-12 Education: Understanding the Status and Improving the Prospects.” It acknowledged that “K12 engineering education is still in its infancy in the United States,” but went on to conclude, “The available evidence shows that engaging elementary and secondary students in learning engineering ideas and practices is not only possible, but can lead to positive learning outcomes”. [2]

Engineers develop problem solving skills that enable them to solve authentic problems. To replicate this process at the precollege level, the use of problem-based learning is an effective tool that affords young students an opportunity to experience some of what engineers encounter. Problem-based learning “teaches students 21st century skills as well as content. These skills include communication and presentation skills, organization and time management skills, research and inquiry skills, self-assessment and reflection skills, and group participation and leadership skills.” [3]

Internet Science and Technology Fair

For the past fifteen years, the University of Central Florida has incorporated problem-based learning into the design of a small, but growing national technology literacy program that challenges young students to explore STEM fields of study while developing 21st century skills. It is called the Internet Science and Technology Fair (ISTF) and is housed at UCF’s College of Engineering and Computer Science (CECS) Outreach Office. The ISTF program’s primary goal is to inspire students to consider engineering and other STEM careers and better understand the innovation process.

ISTF student teams in grades 3-12 explore how National Critical Technologies [4] may be used to solve real world problems. For a period of four months, they use information technology (IT) tools to communicate, research, collaborate, and design innovative solutions while adhering to content guidelines based on national science content standards. They are required to locate an engineer, scientist or technical professional as an online mentor for the duration of their work. Each team presents their research findings in a website format for preliminary and final rounds of judging. During the last 6 years, 600 to 900 students have participated each year from schools in as many as eight states and three countries.

The framework used to guide students through problem solving is predicated on the first four steps of the engineering design process. While acknowledging there are variations on the multiple steps in the engineering design process, for purposes of the ISTF, the steps include:

- identify the need or problem;
- research the need or problem;
- develop possible solutions; and
- select the best possible solution.

In addition to the student teams' numerous screens of research using hyperlink documentation to notate original sources, each team is required to provide a digital design of their innovation. They are also required to complete a team assessment of skills they developed relating to *teaming and communication* and *research and innovation.* Finally, they must identify important *lessons learned.*

Table 1 is a synopsis of key data that provides some perspective on the problem-solving experiences of student teams that participated during the 2011-2012 ISTF competition cycle. Originally, 157 student teams began the process with only 120 completing their research projects, for a 76% completion rate. Most of the student teams were high school level teams, as noted below.

Table 1. Grade Levels of Students and Teams

By Grade Grouping	Elementary Grades 3-5	Middle Grades 6-9	High Grades 10-12	Total
# Project Teams	6 (3.6%)	33 (19.6%)	118 (70.2%)	157
# Students	43 (6.5%)	141 (21.4%)	475 (72.1%)	659

The subsequent analysis presented here is based on the student teams that finished the competition, and relating to their:

- research focus and technology selections;
- feedback from students who responded to the ISTF Final Process Evaluation (that each student is required to complete); and
- student team assessments that addressed thinking skills developed.

Research Focus and Technology Selections

The National Critical Technologies list used by ISTF consists of seven major categories and a multitude of sub-technology categories. Student teams must select a category and subcategory as the focus of their ISTF research project and explore how it might be used to solve a real world problem.

Table 2 shows the technology categories the students selected and some of the more popular sub-technology areas they researched during the 2011-2012 ISTF competition cycle.

Table 2. Student Team Technology Areas

Major category	# projects	Popular sub-technology categories	# projects
Energy	27	Building Technologies	3
		Renewable Energy	14
Environmental Quality	18	Pollution Control	12
		Remediation and Restoration	5
Information & Communication	20	Autonomous Robotic Devices	4
		High-Density Data Storage	2
Living Systems	24	Bacterial/Viral Detection/Screening	2
		Medical Devices and Equipment	15
Manufacturing	6	Pollution Avoidance	2
		Robotics	1
Materials	8	Highway/Infrastructure Materials	2
		Stealth Materials	2
Transportation	17	Aircraft/Spacecraft Avionics	3
		Intelligent Transportation Systems	5
Total projects	120		

Student Feedback from Final Process Evaluation

More than 200 students completed the ISTF Final Process Evaluation. In teaming up, 45% of those students determined who would be on their team, while 28% selected teams based on project focus, with the remainder assigned to a team by their teacher. Narrowing the project focus was a problem for 38% of the student teams. During the competition, 35% of the student teams changed their research focus because their interests changed.

The following are some anecdotal comments the students made on the process of organizing:

- *"We discussed a particular topic and narrowed out ideas to a select few that could possibly work. After, we chose one particular idea as our project focus and split work amongst the group members."*
- *"We gathered in our science teacher's room after school, regularly met on weekends to work on our project, talked about it on our free time, and had asked our science teacher for minor, final suggestions."*
- *"We wanted to do a project related to a problem the world was facing today. We asked our teacher and he told us that the three problems the world was facing was energy shortage, water scarcity and global warming. We decided to do a project that will help with global warming and since fossil fuels are a major contributor to pollution so we wanted to obtain a fuel that is very eco-friendly without killing anything."*

The student teams identified three main problem areas: (1) locating useful information on the Internet; (2) delegating responsibilities; and (3) finding time to work together. Regarding advisors, 68% of the student teams located online technical advisors. These were the key contributions of the advisors: (1) explaining how the project would or would not work; (2) asking important questions to help teams stay on focus; and (3) providing information and useful websites. Some 91% of the students reported being mostly or completely satisfied with their final ISTF project websites, with 75% of the students receiving a grade for their project.

Overall, the ISTF program continues to meet its primary goal of inspiring students to consider engineering and other STEM careers and better understand the innovation process, while enabling students to develop important 21st century skills:

- 67% reported they learned how to work as a part of a team;
- 64% learned time management skills; and
- 46% said the ISTF was helpful in developing research skills.

We continue to witness the impact the program had on students' perceptions related to what they learned about future technical careers, as follows:

- 44% indicated they learned about interesting careers in science and technology;
- 40% felt better prepared to enter mathematics, science, and/or technology courses in the future;
- 37% became more aware of the importance of a specific technical field; and
- 23% believed the ISTF influenced their future career decisions.

The following comments exemplify student perceptions of their future technical careers:

- *"I want to pursue a career in civil engineering because I like to solve problems for people on a larger scale, and as a civil engineer I will get that chance to help people with certain problems they might have."*
- *"It showed me how vast science is and how interesting it is. Before this project, I was not that interested in science, but now I want to establish a career in science."*
- *"It helped me understand that, in the science world, there are so many possibilities and careers. Looking at all the other projects from the previous year and working on our own ISTF made me realize how interesting science and technology could actually be."*
- *"The ISTF has offered a wide variety of topics available from science and engineering programs. When we select one, we had to solve the problem we stated so we can propose a new product and send it to the company we chose via email. This will affect a possible career."*
- *"This project enabled me to learn more about fields in technology, and how they influence our world. It allowed me to use a creative way to develop a new piece of technology, and I found this very intriguing. I am considering this field to be my future career field."*

Student Team Assessments: Developing 21st Century Skills

The following discussion provides a closer look at 21st century skills students developed relating to: (1) teaming and communication; (2) research and innovation; and (3) lessons learned.

This analysis was made possible via funding from the Florida Space Grant Consortium [5] to integrate NAE's Grand Challenges for

Engineering [6] into the ISTF and to analyze what the student teams reported in the assessment portion of each team's final project website. The analysis below is predicated on key areas that represent a majority of student team responses.

Teaming and Communication: The first portion of each team's assessment addressed Teaming and Communication. The teams first identified factors contributing to teamwork, then factors contributing to communication.

High school team comments on **Teamwork** related to the delegation of responsibilities and functioning as a team:

- **Delegation of responsibilities** – *"By dividing different tasks among us according to our individual talents we created a very productive work environment". – "While we all had our own separate jobs, we made sure to consistently check up on others."*
- **Functioning as a team** – *"We all had different interests and trying to agree on a final topic was probably the hardest part for us." – "We started to work as a team and got to know the strengths and weaknesses of each other."*

Middle school team comments on teamwork related to developing a sense of respect and learning the importance of meeting deadlines:

- **Developing a sense of respect** – *"Respect for each other can lead to success. If we had not respected all of our ideas, we would not have gotten our work done as efficiently." – "We learned on the journey of working together to respect each other's views and create a good communication internally within the group."*
- **Learning the importance of meeting deadlines** – *"There were times some of the team members would not do what was needed and complete the tasks by the deadlines we set for ourselves." – "As a resolution, a list was created to assign and record which group member was in charge of completing which task. With this new list and better understanding of expectations, work was done in a much more timely and efficient fashion."*

Elementary school team comments on teamwork related to learning to work together and the importance of technical support:

- **Learning to work together** – *"When we first started working on our project, it was pretty hard to work as a team. We were quite clueless. We didn't work together, we worked independently."* – *"Since we have been working together for a long time, we have new friends and have grown to help each other."*
- **Importance of technical support** – *"Since we didn't know the technical advisor personally, we had to be very detailed when we wrote to him. He helped us a lot with improving our design. It was new and interesting to actually talk to an engineer. It made us feel very 'sciency.'"*

The students identified a number of factors related to **Communication.**

High school team comments on communication related to using technology to manage communication and the role of the teacher/mentor in communicating:

- **Using technology to manage communication** – *"Together we came to a consensus that we would use Google© Documents as a medium of communication for this project"* – *"One way was through Moodle, an online document sharing program through Google and Anoka-Hennepin school district."*
- **Role of teacher/mentor in communicating** – *"The communication between our group and our teacher was open, and we could ask questions when needed."* – *"Also, communication with our mentor helped us to refine our ideas and set goals for our project."*

Middle school team comments on communication related to the cost of not communicating and using multiple forms of communication:

- **Cost of not communicating** – *"Our communication was a little off in the beginning because we didn't communicate as much as we needed to."* – *"The lack of proper communication between team members led to high levels of dysfunction."*
- **Using multiple forms of communication** – *"Our team communicated by using text messages, Facebook, and communicating in school."* – *"Outside school, our group members and our teacher mentor were in touch through phone, email, and sometimes Skype."*

Elementary school team comments on communication related to learning how to listen and staying focused:

- **Learning how to listen** – *"In the beginning, we had a hard time listening to each other but things have changed so we could get work done." – "At first, we were afraid to share ideas that might not make sense or be accepted by the group."*
- **Staying focused** – *"Sometimes we would get off-topic because we were having so much fun with each other." – "We had never worked together on research before so we wanted to talk about fun things."*

Research and Innovation: It was more difficult for the teams to assess Research and Innovation, as many of the teams were working on research projects for the first time, with innovative designs being an outcome.

High school team comments on research and innovation related to the importance of locating dependable information and learning how to innovate:

- **The importance of locating dependable information** – *"The hardest part was probably finding sufficient, true information from trustworthy sites." – "We spent countless hours checking and rechecking sources for accuracy, and got a real taste of the grueling work that goes behind scientific investigation."*
- **Learning how to innovate** – *"We also learned that when you're innovating a solution to a real world problem, that you don't always have to solve a huge problem; sometimes solving a smaller problem will help solve the huge problem later on." – "Just because it seems impossible, doesn't mean that it won't be possible in the future. There is years of research and trial and error, which most people do not really consider until you are put in the situation."*

Middle school team comments on research and innovation related to learning research skills and problem solving:

- **Learning research skills** – *"Our research was not only done through internet but also from interviewing different people who knew something about our related topic." – "Researching is a skill that is needed all throughout life."*
- **On problem solving** – *"When starting this project, we did not realize how unrealistic our idea was and how many gaps were in our design." – "One thing that our team learned was that in order to solve a real world problem, it takes a lot of time and*

focus to combine all of the sources that we gathered to create a working solution."

Elementary school team comments on research and innovation related to finding useful information and developing solutions:

- **Finding useful information** – *"We learned many things about researching through the ISTF program. Our knowledge of safe and appropriate websites helped us learn where to find the right information." – "We didn't always know what to search for and when we tried searching for specific things all sorts of random stuff would come up."*
- **Developing solutions** – *"When it came to innovating a solution, we had a lot of fun coming up with ideas. The only problem was we had too many ideas and just kept adding to them. We finally decided to mash our best five ideas together." – "Many of our ideas were not possible with the technology we have today. Our design changed many times in this process, and we are proud of our final product."*

Lessons Learned: Identifying lessons learned provided insights into what the student teams' valued most from their ISTF experience. Almost every student team cited the value of "teamwork" and "communication" in their team assessments. The teams also related the following as important lessons learned.

High school teams reported lessons learned on the cost of procrastination. They also noted that managing time and organization are keys to success:

- **Cost of procrastination** – *"If everything is left until the last minute, then it looks sloppy and seems like little effort is put into it." – "In the beginning, we procrastinated, and it was very stressful. It is best to get things done as quickly and efficiently as possible."*
- **Managing time and organization is key to success** – *"We wasted time that could have been used more wisely. As a result, it took us longer than it should have to complete each task." – "For the project to succeed, everyone needs to be organized. They need to know what their tasks are, and complete them."*

Middle school students reported lessons learned on being persistent and the value of collaboration, as follows:

- **Being persistent** – *"The second lesson we learned was the need to stay on topic. As 9th graders, we tended to get very off topic, very quickly. This project required us to stay focused and on topic." – "A research project takes time and focus, it can't be rushed."*
- **Value of collaboration** – *"Collaboration is what we need to make our ideas come together." – "Without the collaboration and communication of group members, half the people in the group would not even understand the concept of our invention."*

Elementary school teams reported these lessons learned on the value of science content and contributions of technical professionals:

- **Value of science content** – *"The most important lesson we gained knowledge on was probably the science content we needed to solve our problem." – "One of the three lessons that we learned is some of the science behind polymers and a little bit about chemistry."*
- **Contributions of technical professionals** – "*We only worked for a short time compared to the engineers and scientists. They experiment and change solutions over years sometimes."*

Conclusion

As one student reported in the final process evaluation, "*To conclude, the ISTF project was very beneficial to essential skills that we must learn in life."*

Inasmuch as problem solving, teaming and communication are important skills used in engineering, they must be incorporated into the learning process for young students to develop 21st century skills they will need for the workplace and to function in society. To this end, the ISTF will continue to provide an informal learning opportunity for precollege students in and outside the classroom. We are most grateful to the many teachers and technical professionals who have dedicated their time and talents in support of the program.

Citations

1. "Engineers: How are you Changing the Conversation?" National Academy of Engineering of the National Academies, Web n.d.
2. National Research Council. "6 Findings and Recommendations." Engineering in K-12 Education: Understanding the Status and Improving the Prospects. Washington, DC: The National Academies Press, 2009. 1. Print.
3. "Project Based Learning." The Buck Institute for Education and Boise State University, Department of Education Technology, Web n.d.
4. "National Critical Technologies List," National Science and Technology Council, Web. 5 August 1993.
5. "Florida Space Grant Consortium," NASA sponsored program administered by the University of Central Florida, Web. 25 April 2012.
6. National Academy of Engineering, Grand Challenges for Engineering, n.p. Web. 10 May 2012.

Analysis of the Motion of a Ball in the Barrel of a Musket

Carl E. Mungan and John S. Denker

U.S. Naval Academy, Annapolis, MD

Abstract

The one-dimensional motion of a particle is analyzed when the force on it is inversely proportional to its displacement and directly proportional to the elapsed time. Such a force law describes a projectile in a musket barrel that is propelled by a hot ideal gas where either the number of moles or the temperature increases linearly with time due to the burning gunpowder. A particular solution to Newton's second law is found analytically for the case of zero initial position and velocity. For more general initial conditions, numerical integration is used to find the position of the particle as a function of time. A scaling argument shows that at long times, these numerical general solutions all converge to the analytic particular solution. Further analysis reveals how that convergence occurs: the general solutions slowly oscillate about the particular solution with a predictable period and amplitude. In addition to the dynamics, the energetics of the motion are analyzed.

Basic Dynamics of the Ball in a Musket

A LEAD BALL of mass m is tamped down the barrel of a musket of cross-sectional area A, so that it rests against a layer of black powder with initial position $x_0 = 0$ and velocity $\upsilon_0 = 0$, as sketched in Figure 1. Model the system by making three assumptions that simplify the analysis and bring out its essential features. First, suppose [1] the powder burns at a constant rate r, creating n moles of hot gas at temperature T as a function of time t, so that

$$n = rt. \tag{1}$$

Second, assume that the gas expands isothermally [2] as the ball proceeds down the barrel, so that T is constant. Third, neglect the losses: Suppose that there is no friction between the barrel and the sliding ball, but at the same time assume the ball fits tightly enough that there is no leakage of gas around it [3]. (Historically, lead shot would often be wrapped with linen to prevent gas from escaping while minimizing the coefficient of

friction.) Also suppose that the atmospheric back pressure on the ball can be ignored compared to the forward gas pressure.

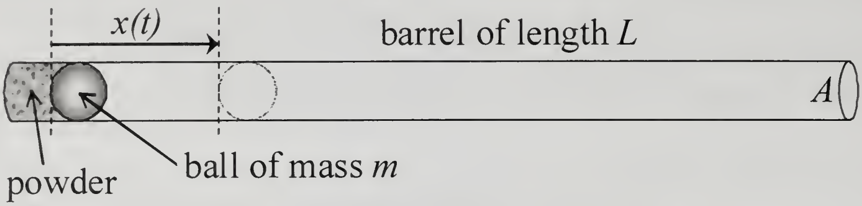

Figure 1. Ball in the Barrel of a Musket.

The gas pressure P is then related to the net force F on the ball by the definition of pressure as force per unit area, $P = F / A = ma / A$, where a is the acceleration of the ball along the barrel using Newton's second law. Furthermore, the volume of the gas is given by $V = Ax$ where x is the displacement of the ball (cf. Figure 1), and thus $PV = max$. Treating the gas as ideal, *i.e.*, $PV = nRT$ where R is the gas constant, it follows that

$$xa = kt \tag{2}$$

using Equation (1), where k is the positive constant

$$k = \frac{rRT}{m}. \tag{3}$$

Substituting $a \equiv d^2x / dt^2$, Equation (2) becomes a nonlinear inhomogeneous differential equation for the position of the ball as a function of time, $x(t)$. A particular solution of it can be immediately found using the trial form

$$x = Bt^N \tag{4}$$

where B and N are constants to be determined. By substituting Equation (4) into (2) and equating both the powers and prefactors of t on the two sides of the equation, one finds

$$N = \frac{3}{2} \quad \text{and} \quad B = \sqrt{\frac{4k}{3}}, \tag{5}$$

so that

$$x = \left(\tfrac{4}{3}k\right)^{1/2} t^{3/2}. \tag{6}$$

The first and second time derivatives of this result give the velocity and acceleration of the ball as a function of time,

$$v = \sqrt{3kt} \tag{7}$$

and

$$a = \sqrt{\frac{3k}{4t}}. \tag{8}$$

Equation (6) is not the general solution of Equation (2) because it does not include two arbitrary integration constants. Instead it is the particular solution corresponding to $x_0 = 0$ and $v_0 = 0$ (which happily is the case most relevant to a ball in a musket). Later in this article we will consider how to find solutions for other initial conditions (see the section, "General Solution of the Differential Equation," below).

The ball is in the barrel during the time interval from $t = 0$ until some later time $t = t_{\max}$. Equations (6) and (7) then imply that the length of the barrel is

$$L = \left(\tfrac{4}{3}k\right)^{1/2} t_{\max}^{3/2} \tag{9}$$

and the muzzle velocity of the ball is

$$v_{\max} = \sqrt{3kt_{\max}}. \tag{10}$$

Equations (9) and (10) are two equations in two unknowns (k and $t_{\max}$) if L and $v_{\max}$ are measured. For example, the 58 Springfield musket [4] has a barrel length of 1 m and a muzzle velocity of 290 m/s, from which one deduces that $k = 5.4\ \text{km}^2/\text{s}^3$ and $t_{\max} = 5.2$ ms. Equations (6) to (8) are plotted in Figure 2 for these values. Although the acceleration initially diverges, the velocity and position are nevertheless well defined at all times. The rise in the velocity quickly tapers off, demonstrating that there is little advantage in increasing the barrel length past a certain point. (In particular, if losses were included, there would be some definite optimal length for a given powder charge.)

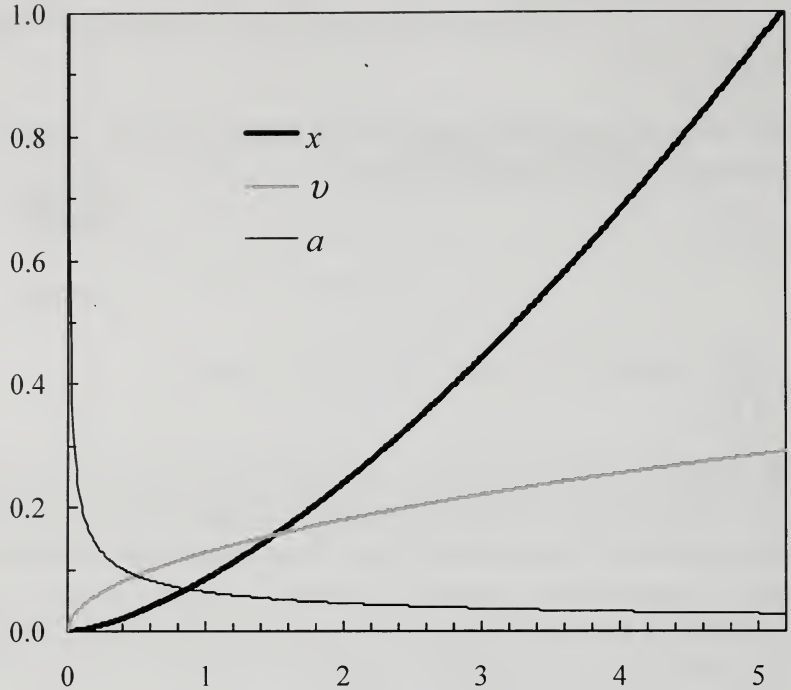

Figure 2. Graphs of x (in m), υ (in km/s), and a (in m/ms^2) versus t ranging from 0 to 5.2 ms if $k = 5.4\ \mathrm{km}^2/\mathrm{s}^3$ for the initial conditions $x_0 = 0$ and $\upsilon_0 = 0$.

Energetics of the Powder, Gas, and Projectile

The derivation of Equation (2) above depends on the fact that nRT increases linearly with time t. Specifically, it was assumed that T is constant and that $n = rt$. Hot gas is created (starting from zero moles) by chemical conversion of the solid powder. For simplicity, consider the gas to be monatomic. An alternative way to model the system is to take n to be constant, while $T = rt$, *i.e.*, the temperature is no longer constant. One could now think of the gas atoms as initially existing latently in the gunpowder in condensed form (which classically corresponds to absolute zero temperature) and that they get rapidly warmed up by thermal energy transfer Q from the burning charge.

Reversible thermodynamics can be used in the analysis because the gas expansion is quasistatic and there are no dissipative losses. Appendix A shows that the gas is always in quasi-equilibrium by treating the expansion of the gas behind the ball like the familiar example of a piston

in a frictionless cylinder. The piston slides slowly compared to the speed of sound, provided that its mass is much larger than that of the gas.

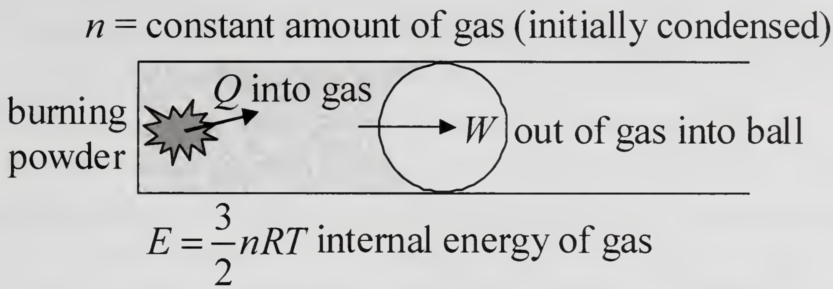

Figure 3. Relevant energy transfers between the gunpowder, propelling gas, and musket ball in the model where the number of moles n of the gas is taken to be constant and its temperature T increases linearly.

The energetics of the musket are now analyzed by reference to Figure 3. Consider an arbitrary interval of time between 0 and t. During this interval, the monatomic gas ends up with an internal energy [5] of $E(t) = 1.5nRT(t)$, whereas it started with no internal energy when condensed. Thus the change in internal energy of the propellant gas is

$$\Delta E = \frac{3}{2} nRT . \tag{11}$$

During this time, the gas does work W on the ball, calculated from

$$W = \int F dx = m \int a dx \tag{12}$$

(or equivalently from $\int P dV$.) One could proceed by substituting Equations (6) and (8) to convert the last result into a time integral that can be performed. A simpler and more general approach is to use the definitions of velocity and acceleration to rewrite Equation (12) as

$$W = m \int \frac{dv}{dt} v dt = \frac{1}{2} m \Delta \left(v^2 \right) = \Delta K \tag{13}$$

where $K \equiv \frac{1}{2} m v^2$ is the kinetic energy of the ball. Equation (13) is

simply a derivation of the work-kinetic-energy theorem of the ball since it is treated here as a particle. For the particular solution of interest (which is also the asymptotic solution for large times for any choice of initial conditions, as is proven in the section below, "Scaling Argument to Find the Asymptotic Behavior"), Equations (1), (3), and (7) can be substituted into this result to obtain

$$W = \frac{3}{2} nRT . \tag{14}$$

Finally, the first law of thermodynamics applied to the gas implies that

$$\Delta E = Q - W \quad \Rightarrow \quad Q = 3nRT \tag{15}$$

using Equations (11) and (14). In words, these results prove that energy is being transferred from the powder to the gas and projectile at the constant rate $dQ / dt = 3nRr$. Half of that added energy goes into warming up the gas, increasing its internal energy, while the other half goes into accelerating the ball, increasing its translational kinetic energy. Thus the energy transfer efficiency from the powder to the ball is 50% even for this ideal musket.

General Solution of the Differential Equation

In this section we explore the nonlinear differential equation $xa = kt$ from a more general mathematical point of view. The physical application presented above helps interpret these general numerical results.

Reparameterizing the Equation

Equation (2) is second order and so its general solution must contain two constants of integration, corresponding to the initial position x_0 and initial velocity υ_0, in addition to the adjustable value of k. In total, there are thus three parameters in the family of solutions. However, some of these parameters can be eliminated by rescaling the units of length and time. This reparameterization is performed in different ways, depending on the initial conditions.

Choose the $+x$ axis to point in the direction of motion of the particle at long times. Then for $k > 0$, the position of the particle can never be negative. Appendix B discusses what happens if the ball is launched toward the origin and shows that x cannot reach (or cross) zero

no matter how large the initial speed is. The particle is repelled from the origin and must eventually move in the positive x direction, either because it initially started moving in that direction or because it reversed direction after exactly one bounce.

Therefore, at times t other than zero, the position x must always be strictly positive. In contrast, at $t = 0$ the initial position x_0 can be either positive or zero. For example, Equation (2) indicates that x_0 can be nonzero if the initial acceleration is zero, whereas Equation (6) applies to the special case $x_0 = 0$. If $x_0 = 0$, then the initial velocity υ_0 cannot be negative, because otherwise the particle would thereafter move in the direction of negative x, contrary to our choice of axis. The various possible initial conditions can therefore be divided into three classes.

Class A: x_0 is positive and υ_0 is arbitrary

Define a characteristic length $\tilde{x} \equiv x_0$ and a characteristic time $\tilde{t} \equiv x_0^{2/3} k^{-1/3}$. These two quantities can be used to define a characteristic speed $\tilde{\upsilon} \equiv \tilde{x} / \tilde{t} = x_0^{1/3} k^{1/3}$ and a characteristic acceleration $\tilde{a} \equiv \tilde{x} / \tilde{t}^2 = x_0^{-1/3} k^{2/3}$. In effect, the units of distance and time have been chosen to scale away x_0 and k, reducing the three-parameter family of solutions to a form that depends only on υ_0.

Class B: x_0 is zero but υ_0 is positive

Now define the characteristic length as $\tilde{x} \equiv \upsilon_0^3 k^{-1}$ and the characteristic time as $\tilde{t} \equiv \upsilon_0^2 k^{-1}$. Then the characteristic speed is $\tilde{\upsilon} \equiv \tilde{x} / \tilde{t} = \upsilon_0$ and the characteristic acceleration is $\tilde{a} \equiv \tilde{x} / \tilde{t}^2 = \upsilon_0^{-1} k$. That is, the units of distance and time have been chosen to eliminate υ_0 and k. Given that $x_0 = 0$, the family of solutions to Equation (2) reduces to zero adjustable parameters with two specified initial conditions.

Class C: both x_0 and υ_0 are zero

In this case, there is only one parameter in the original problem and so we cannot independently define both a characteristic length and time. Arbitrarily choosing $\tilde{x} \equiv 1$ m in base SI units, then $\tilde{t} \equiv \tilde{x}^{2/3} k^{-1/3}$, $\tilde{\upsilon} = \tilde{x}^{1/3} k^{1/3}$, and $\tilde{a} \equiv \tilde{x}^{-1/3} k^{2/3}$. This class corresponds to the particular

solution already found in the first section of this paper, "Basic Dynamics of the Ball in a Musket."

For any of the three classes, dimensionless kinematic variables can be introduced as $t' \equiv t / \tilde{t}$, $x' \equiv x / \tilde{x}$, $\upsilon' \equiv \upsilon / \tilde{\upsilon}$, and $a' \equiv a / \tilde{a}$. In terms of these dimensionless variables, Equation (2) becomes

$$x'a' = t' \tag{16}$$

where $\upsilon' = dx' / dt'$ and $a' = d\upsilon' / dt'$. The initial conditions for class A are $x_0' = 1$ and $\upsilon_0' = x_0^{-1/3} k^{-1/3} \upsilon_0$. The differential equation has thus been recast in a form that only depends on the single combined value υ_0'. That makes it easier to investigate and plot its family of solutions. For class B, the initial conditions are uniquely specified as $x_0' = 0$ and $\upsilon_0' = 1$. Using l'Hôpital's rule, the initial acceleration is then $a_0' = 1$.

Numerical Solution

Equation (16) has no discernible closed-form analytic solution in general, but one can numerically integrate it. Different methods can be used for this purpose, depending on the desired accuracy and ease of calculations. To start with, the first-order Euler-Cromer method [6] can be implemented in a spreadsheet. Given values x_i' and υ_i' at any time t_i', their values at the next time step $t_{i+1}' = t_i' + \Delta t'$ (where $\Delta t' = 0.1$ say, corresponding to a time step in real units of $\tilde{t} / 10$) are sequentially calculated as

$$\begin{aligned} \upsilon_{i+1}' &= \upsilon_i' + a_i'\Delta t' = \upsilon_i' + \left(t_i' / x_i'\right)\Delta t' \\ x_{i+1}' &= x_i' + \upsilon_{i+1}'\Delta t' \end{aligned} \tag{17}$$

with starting values for class A of $t_0' = 0$, $x_0' = 1$, and any chosen value of υ_0'. The results are plotted as the solid curves in Figure 4 for four values of υ_0'. A similar numerical integration for class B (when $x_0' = 0$, $\upsilon_0' = 1$, and $a_0' = 1$) results in a curve that is almost indistinguishable from the dashed curve (corresponding to class C).

The equation for x_{i+1}' involves the updated velocity υ_{i+1}' rather than the previous value υ_i', in contrast to the equation for υ_{i+1}' which uses the previous value of the acceleration a_i'. That is the hallmark of Cromer's

modification of the standard Euler method, classified as a symplectic integrator. Symplectic methods are the preferred choice when the Lagrangian L has no explicit time dependence, but they can be used even when L is time dependent (as is shown in Appendix C to be the case here). By comparison with the results of the second-order leapfrog integration in Appendix D, the Euler-Cromer method obtains values of position and velocity that are found to be accurate to 0.4% or better, so Equation (17) suffices to generate Figure 4.

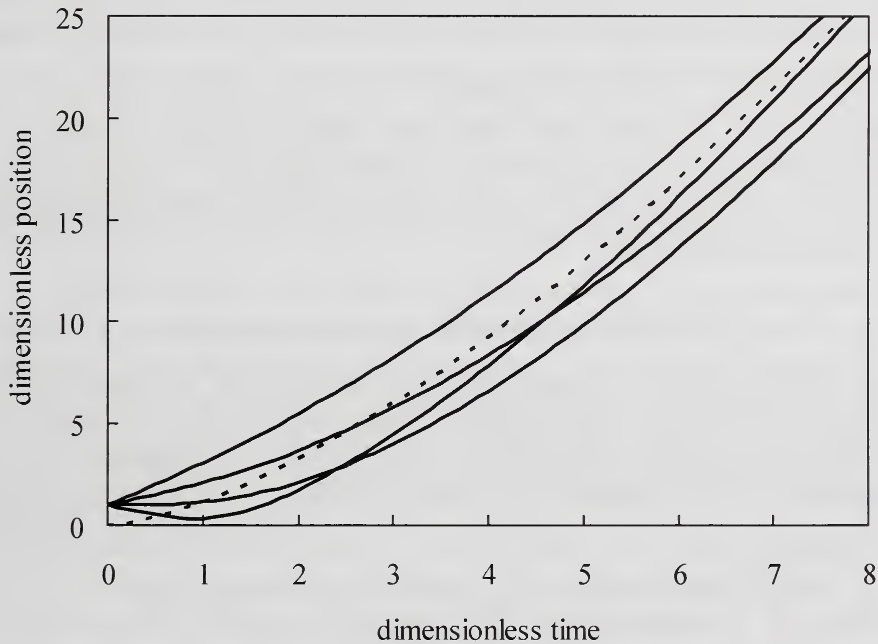

Figure 4. Graphs of x' versus t'. The four solid curves were calculated numerically using Equation (17) for $x'_0 = 1$ and v'_0 equal to 2, 1, 0, and -1 (from top to bottom at $t' = 1$). The dashed curve is a plot of Equation (18).

Scaling Argument to Find the Asymptotic Behavior

The dashed curve in Figure 4 is a plot of the solution represented by Equation (6) in dimensionless form,

$$x' = \sqrt{\tfrac{4}{3}}\, t'^{3/2} \tag{18}$$

which is the particular solution of Equation (16) for class C, *i.e.*, initial

values $x'_0 = 0$ and $v'_0 = 0$. To investigate how Equation (18) relates to the numerical results in the "Numerical Solution" section above, introduce new variables $x'' \equiv x'/s^3$ and $t'' \equiv t'/s^2$ where s is an arbitrary positive scaling factor that zooms Figure 4 in or out (albeit not equally for the two axes). Defining $v'' \equiv dx''/dt''$ and $a'' \equiv d^2x''/dt''^2$, Equation (16) becomes

$$x''a'' = t'' \tag{19}$$

with initial conditions $x''_0 = x'_0/s^3$ and $v''_0 = v'_0/s$. Then if $s \to \infty$, the solution corresponding to $x''_0 = 0$ and $v''_0 = 0$ is obtained, namely $x'' = (4/3)^{1/2}\,t''^{3/2}$. Therefore Equation (18) is an asymptotic solution of Equation (16) at large times for *any* initial values. To verify that conclusion, Figure 4 was replotted with the range of t' values increased 25-fold. On this expanded scale, the solid curves are indistinguishable by eye from the dashed curve.

Oscillations about the Asymptotic Solution

To quantify the manner in which the general solutions approach the asymptotic curve, dimensionless residuals $\Delta x'$ are computed by subtracting the analytic particular solution given by Equation (18) from any solution $x'(t')$ computed numerically. Whenever a numerical solution has a smaller value of x' (at a given t') than the asymptotic solution, it has a larger acceleration (*i.e.*, second derivative), and vice-versa, according to Equation (16). The numerical solution thus repeatedly catches up to and crosses the asymptotic curve, oscillating about it. It is found that these oscillations have both increasing period and increasing absolute amplitude.

A physical explanation for these oscillations can be found in the ballistic situation of the first section, "Basic Dynamics of the Ball in a Musket." If the ball gets ahead of the position it has in the particular solution at the same time, the gas becomes under-pressured in comparison and the ball's acceleration drops. That permits the gas pressure to "catch up," but the inertia of the ball leads to an overcorrection, and the cycle now reverses.

Returning to the residuals, the amplitude of $\Delta x'$ is proportional to $\sqrt{t'}$ as $t' \to \infty$, according to the analysis in Appendix D. Therefore the *relative* amplitude of the oscillations, $\Delta x'/x'$, decreases to zero in

proportion to $1/t'$ for large times. In this relative sense, solutions of Equation (16) for any initial conditions converge onto the asymptotic solution, Equation (18).

Conclusions

The force law described by $xa = kt$ has a simple form but exhibits rich behavior. Physically, it describes the idealized motion of a ball in an unrifled musket. Another situation that gives rise to Equation (2) is the radial motion of a particle (of mass m and charge q) in the electric field of a long straight wire whose linear charge density is proportional to time, $\lambda = \alpha t$. Then $k = \alpha q / 2\pi e_0 m$ (where e_0 is the permittivity of free space), which allows the possibility of a negative value of k that the ballistic application does not. Investigation of the motion for $k < 0$ could make an interesting student project. Further study of the equation $a \propto t/x$ may uncover additional applications and intriguing behavior.

Mathematically, the solution of Equation (2) involves power-law behavior (of the particular solution), oscillatory behavior (of the residuals), and exponential behavior (of the intervals between zero crossings of the oscillations). It calls for a diverse combination of analysis techniques, including insights from physics, trial solutions of differential equations, scaling laws, graphical methods, algebraic approximations, and computational algorithms.

Appendix A: Quasistatic Expansion of the Gas Pushing the Ball in the Barrel

At long times (if not initially), the speed of the musket ball is given by the slope of the dashed curve in Figure 4, obtained by substituting Equation (3) into (7) to get

$$\upsilon_{\text{ball}} = \sqrt{\frac{3nRT}{m_{\text{ball}}}} \tag{A.1}$$

after replacing $n = rt$ from Equation (1). Here the subscript "ball" has been added to υ and m to emphasize that those two variables refer to the speed and mass of the projectile specifically. On the other hand, the root-mean-square speed of the atoms in a monatomic ideal gas is known from kinetic theory or equipartition [5] to be

$$v_{\text{gas}} = \sqrt{\frac{3nRT}{m_{\text{gas}}}} \tag{A.2}$$

where m_{gas} is the total mass of the gas in the musket. (The speed of sound has almost the same value, obtained by replacing the factor of 3 in this equation by the adiabatic exponent $\gamma = 5/3$.) Comparing Eqs. (A.1) and (A.2), one sees that the speed of the ball will always be small compared to typical molecular speeds provided that the mass of the ball is much larger than the total mass of the gas. In that case, the gas expansion is said to be quasistatically slow.

Appendix B: Motion of the Ball for Negative Initial Velocities

One cannot compress the volume of the gas in the barrel to zero (at nonzero temperatures). However, if one runs the Euler-Cromer simulation specified by Equation (17) with say $v_0' = -3$ and $\Delta t' = 0.1$, the trajectory appears to cross the horizontal axis (near $t' = 0.34$) and become increasingly negative thereafter. This zero crossing is an artifact of inaccurate numerical integration. It only occurs when the time step is large enough that the simulation can "jump" over the divergence in the repulsion that occurs at $x' = 0$. We can prove that such a jump does not occur for infinitesimally fine time steps as follows.

Consider the specific work, i.e., work per unit mass, $\int a'dx'$ as the ball approaches $x' = 0$. Then t' is approximately constant (for example at about 0.34 if $v_0' = -3$) during the small time interval that x' is smaller than some initial value x_i', say 0.1. Now according to the work-kinetic-energy theorem,

$$v'^2 - v_i'^2 = 2\int_{x_i'}^{x'} a'dx' \approx 2t' \ln \frac{x'}{x_i'} \tag{B.1}$$

using Equation (16). The right-hand side of this equation is negative (because $x' < x_i'$) and thus the ball slows down as it approaches $x' = 0$. But it can never reach $x' = 0$ because the left-hand side can never get smaller than $-v_i'^2$ in value. Consequently, even if the negative initial velocity is very large in magnitude, the ball will necessarily bounce off the (infinite) potential barrier at the origin, as occurs for the curve corresponding to

$\upsilon_0' = -1$ in Figure 4.

Appendix C: Canonical Mechanics of the System

An explicitly time-dependent Lagrangian L and Hamiltonian H can be constructed as follows. Equation (B.1) suggests a potential energy $U(t)$ that is logarithmic in the position and thus

$$L \equiv K - U = \tfrac{1}{2} m\dot{x}^2 + mkt \ln x \tag{C.1}$$

where $\dot{x} \equiv \upsilon$. The momentum conjugate to the position x is

$$p \equiv \frac{\partial L}{\partial \dot{x}} = m\dot{x} \tag{C.2}$$

and thus the Hamiltonian is

$$H \equiv p\dot{x} - L = \tfrac{1}{2} m\dot{x}^2 - mkt \ln x\,. \tag{C.3}$$

Then the equation of motion is obtained from Hamilton's equation as

$$\dot{p} = -\frac{\partial H}{\partial x} \quad \Rightarrow \quad m\ddot{x} = \frac{mkt}{x} \tag{C.4}$$

which rearranges into $xa = kt$. Alternatively, this equation of motion can be obtained from Equation (C.1) using the Lagrange equation

$$\frac{d}{dt}\frac{\partial L}{\partial \dot{x}} = \frac{\partial L}{\partial x}\,. \tag{C.5}$$

Appendix D: Harmonic Oscillations of the Residuals

Dropping the primes so as to unclutter the notation, the dimensionless force law is

$$\ddot{x} = \frac{t}{x} \tag{D.1}$$

from Equation (16), with a particular solution of

$$x_\mathrm{p} = \sqrt{\tfrac{4}{3}}\, t^{3/2}\,. \tag{D.2}$$

Define the residual Δx as the difference between a general solution of

Equation (D.1) for x and the right-hand side of Equation (D.2). Examination of numerical results from Equation (17) suggests that the residual (for any value of the dimensionless initial velocity υ_0) oscillates harmonically in the logarithm of the elapsed time t with an amplitude that increases in proportion to the square root of the time. To verify this suggestion, let the scaled residual z be defined as Δx divided by $\sqrt{t}$, so that

$$z = xt^{-1/2} - \sqrt{\tfrac{4}{3}}\,t \tag{D.3}$$

which can be solved for x to get

$$x = zt^{1/2} + \sqrt{\tfrac{4}{3}}\,t^{3/2}. \tag{D.4}$$

Take the second derivative of this equation with respect to time, and substitute both it and Equation (D.4) into (D.1) to obtain

$$\left(1+\sqrt{\tfrac{3}{4}}\,z/t\right)^{-1} = 1+\sqrt{\tfrac{4}{3}}\left(\ddot{z}t+\dot{z}-\tfrac{1}{4}z/t\right). \tag{D.5}$$

Since it will be shown that the amplitude of the scaled residual z levels off in value asymptotically (cf. Figure 5), z/t must approach zero for large t. Thus the left-hand side of Equation (D.5) can be approximated using the binomial expansion to first order. The result can be rearranged to get

$$\ddot{z}t^2 + \dot{z}t = -\tfrac{1}{2}z. \tag{D.6}$$

The left-hand side of this equation can be identified as the logarithmic second derivative

$$\frac{d^2 z}{(d\ln t)^2} = \ddot{z}t^2 + \dot{z}t\,. \tag{D.7}$$

Therefore Equation (D.6) implies that the (logarithmic) second derivative of z is proportional to $-z$, characteristic of simple harmonic motion. Consequently the residual oscillates semi-logarithmically with a period of $2\pi\sqrt{2}$, *i.e.*, a half-period corresponds to a ratio of adjacent zero-crossings of $z(t)$ that equals $\exp\left(\pi\sqrt{2}\right) \approx 85.02$.

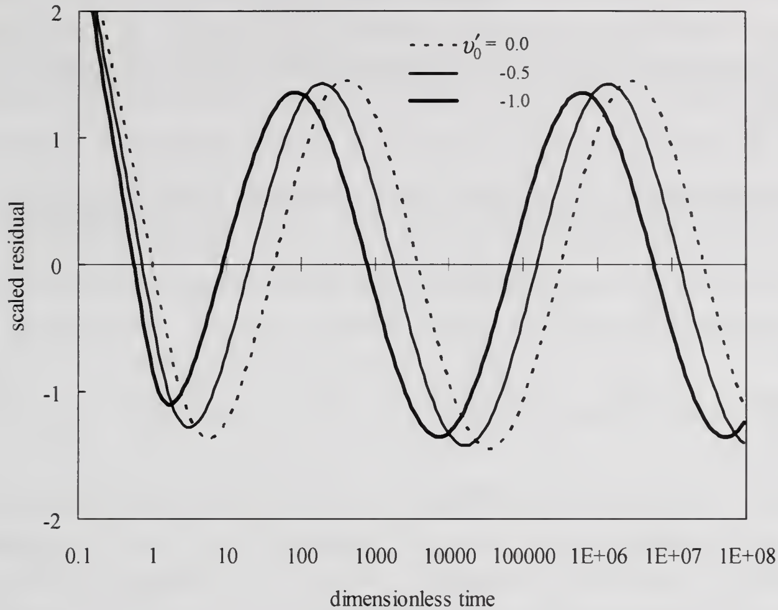

Figure 5. Semi-logarithmic plots of the scaled residual $\Delta x'/\sqrt{t'}$ against the dimensionless time t' for the three indicated values of v_0' with $x_0' = 1$.

Figure 5 plots the scaled residual z as a function of time on semi-logarithmic axes for $x_0 = 1$. The three curves correspond to different values of v_0 between 0 and -1. Zero crossings for these three curves are listed in Table 1. For large t, the ratio between successive zero crossings is in excellent agreement with the asymptotic value 85.02 predicted by Equation (D.6).

The results in Table 1 require x values accurate to better than 1 part in 10^9, because z is a small difference between large numbers. To achieve that level of accuracy, a C++ program [7] was written to calculate the residuals over a longer range of times and with higher accuracy than can be done using the spreadsheet solution. The program replaces the first-order calculations of Equation (17) with the second-order leapfrog calculations

$$x_{i+1} = x_i + v_i \Delta t + \frac{1}{2}\left(\frac{t_i}{x_i}\right)(\Delta t)^2 \quad \text{and} \quad v_{i+1} = v_i + \frac{1}{2}\left(\frac{t_i}{x_i} + \frac{t_{i+1}}{x_{i+1}}\right)\Delta t\,. \quad \text{(D.8)}$$

An adaptive time step size is used: Δt is gradually increased as t increases, to keep pace with the exponential increase in the period of oscillations. An even higher-order symplectic integrator [8] was used as a further check on the results.

Table 1. Zero-crossing times in Figure 5 and their ratios, accurate to 1 part in 10^4, for three different values of the dimensionless velocity.

for $v_0' = -1.0$: zero-crossing time	ratio	for $v_0' = -0.5$: zero-crossing time	ratio	for $v_0' = 0.0$: zero-crossing time	ratio
8.7402		20.493		43.493	
	89.47		87.02		85.98
781.99		1783.2		3739.5	
	84.97		85.00		85.01
66 446		151 570		317 890	
	85.02		85.02		85.02
5 649 300		12 886 000		27 027 000	

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References

[1] M. Denny, *Their Arrows Will Darken the Sun: The Evolution and Science of Ballistics* (Baltimore, Johns Hopkins University Press, 2011) Technical Note 7.

[2] M. Denny, "The internal ballistics of an air gun," *Phys. Teach.* **49**, 81–83 (2011).

[3] C.E. Mungan, "Internal ballistics of a pneumatic potato cannon," *Eur. J. Phys.* **30**, 453–457 (2009).

[4] http://www.hackman-adams.com/guns/58musket.htm .

[5] R. Feynman, R.B. Leighton, and M.L. Sands, *The Feynman Lectures on Physics* (Reading, Addison-Wesley, 1963) Vol. I.

[6] A. Cromer, "Stable solutions using the Euler approximation," *Am. J. Phys.* **49**, 455–459 (1981).

[7] http://usna.edu/Users/physics/mungan/Publications/ratio-gun-eom.c .

[8] E. Hairer, C. Lubich, and G. Wanner, *Geometric Numerical Integration: Structure-Preserving Algorithms for Ordinary Differential Equations*, 2nd ed. (Berlin, Springer, 2006) with codes online at http://www.unige.ch/~hairer/software.html.

Outgoing President's Remarks: State of the Academy

Gerard Christman

It has been an honor and a privilege to serve as President of the Washington Academy of Sciences from May 2011 to May 2012. It has been a wonderful year for the Academy on all fronts: membership, benefits, affiliates, finances, the Junior Academy, and a terrifically vibrant program.

You may not be aware that there has been a downturn in membership in a great many science and engineering societies. With the downturn in the economy, people cut back in memberships and activities. For the past few years the Academy's membership remained stable. This year we experienced an increase in our membership and an accompanying interest in an active role through service on the Board or one of our committees. This was a welcome and refreshing turn of events as it takes a great deal of effort by our volunteers to maintain the Academy as a relevant umbrella organization for our Affiliates.

This year, the Board approved a self-publishing member benefit where interested authors can get their work published with the Academy's imprimatur as a result of rigorous peer review by Academy members who have specialized expertise. The Academy will leverage the lessons learned by its members who have engaged in self-publishing and promulgate guidelines for submitting work for review in the near future.

The Academy added additional Affiliates that have added greatly to our ability to offer members a quality program. Most notable is the National Rural Electric Cooperative Association (NRECA) located in Ballston. With their generous donations in kind, we were able to use their facilities for CapSci12 and for the Annual Meeting and Awards Banquet.

I am pleased to report that the Academy's finances are sound. I am grateful to the Audit Committee for their rigorous review. I am also grateful to those who have graciously donated to one of our many causes or to the Academy generally. I would like to underscore the Academy's gratitude for the generous donation by the Haig estate done in loving memory of General Alexander Haig who passed away in 2010. This was provided for the expressed purpose of payment of office rental expenses at the American Association for the Advancement of Sciences (AAAS)

building in Washington DC. The Living Oceans Foundation provided a very sizable donation to serve as seed money for CapSci. I would also like to recognize the generosity of Peg Kay who also made a sizeable donation to the Academy this year. The Academy received wonderful donations in kind from the George Washington University, Marymount University, and the Virginia Tech Research Institute through the use of the educational facilities on Glebe Road for CapSci12. The Institute of Electrical and Electronic Engineers (IEEE) were generous benefactors this year through their support of the Junior Academy. Additionally, Meadowlark Gardens generously donated free admission passes to their marvelous gardens to all CapSci12 attendees.

I am grateful to Dick Davies for the Junior Academy involvement in a record number of Science Fairs. This resulted in issuing a record number of award certificates to Washington area children for their outstanding science projects. Let us hope that our engagement translates into children becoming interested in a career in science and engineering.

The Academy executed a vibrant program this year. In the Fall we had our annual Affiliates Reception at the National Rural Electric Cooperative Association (NRECA). In late Fall, we enjoyed another installment of Science is Murder at the AAAS building. We thoroughly enjoyed the panel of authors who explained how they became writers and their association with science. The Academy sponsored the fifth biennial CapSci conference with the support of the unprecedented three-university consortium of the George Washington University, Marymount University, and the Virginia Tech Research Institute. I cannot adequately express my gratitude to the many volunteers and the CapSci Committee for conducting the best ever iteration of CapSci. Our plenary and luncheon speakers gave outstanding talks on a range of issues including the science of climate change by Dr. Compton “Jim” Tucker from NASA. Lastly, the Annual Meeting and Awards Banquet was bittersweet in that we recognized Peg Kay on her retirement from Executive Directorship of the Academy but we were honored to be able recognize a giant in the field of Astronomy, Dr. Vera Rubin with an award for her lifetime of achievements and contributions. Despite being in her 80s now, she continues to work and contribute to our understanding of the Universe. I would like to express a special word of gratitude to Dr. Terrell Erikson for Chairing the Banquet Committee and for making it such an outstanding event.

In summary, it has been a great year for the Academy and for me. I have learned a great deal and I am grateful to the Board, our members, and our volunteers for their friendship, comity, and their contributions. I wish the incoming Board every success for the coming year.

Incoming Board of Managers, Washington Academy of Sciences

(from left to right): Frank Haig (member at large), Richard Hill (VP affiliated societies), Sethanne Howard (VP membership), Terrell Erickson (secretary), Gerard Christman (immediate past president), Neal Schmeidler (member at large), Jim Cole (incoming president), Jim Egenreider (president-elect), Cathy With (member at large). Missing from photo: Ron Heitala (treasurer), Jim Disbrow (VP administration), Dick Davies (VP junior academy), Michael Cohen (member at large), Paul Arveson (member at large), and Sally Rood (ex officio journal editor).

Incoming President's Remarks: Next Year at the Academy

James Cole

First, I want to personally congratulate our 2012 award recipients. The selection process is difficult because of the high caliber of all the nominees. Let us all thank our awards committee for their efforts.

All of you in attendance tonight are invited to participate in the academy's other activities by attending our scientific programs, volunteering to judge science fairs for the junior academy or joining one or more of our committees, and please encourage your fellow Affiliate Society members and co-workers to join the academy and to participate in our activities.

Now bear with me as I use my personal history with the Academy as an example that demonstrates the numerous activities of the Academy.

At CapSci 2004, I presented a paper in a session sponsored by the National Capital Section of the Optical Society of America and IEEE Leos which is now the IEEE Photonics Society.

I found that CapSci exposed me to diverse scientific subject matter of high quality. I wanted more!

As an example of the excellent quality of the presentations, at a later CapSci NIST sponsored an excellent session on Quantum Computing which occurred well before the explosion of interest in that field.

Following my first CapSci, Vary Coates, the Academy journal editor at the time, contacted me about including my CapSci paper in the Journal.

My thoughts: "Wow, the Academy has a peer reviewed journal as well!"

I wanted to learn more about the Academy and became an affiliate representative to the Board and a member of the Academy. From there, I learned about the other great programs including the Junior Academy.

As a side note, while cleaning out the long-time New Hampshire home of my step-father's family, I found out that my step-grandfather was a member of the Academy; I always knew he was a smart man!

I find it hard to believe that I have been associated with the Academy for over 8 years!

Now I want to move on to the coming year.

Recently, my predecessors Mark Holland and Gerry Christman have begun an initiative to increase the Academy's activities with undergraduate university students.

This includes forming student chapters of the Academy and encouraging student participation in CapSci.

This year, in addition to our regular programs, the academy will focus on expanding and solidifying Mark and Gerry's efforts.

Finally, as Gerry has already done, I must once again thank Peg Kay for all she has done for the Academy over many years. The Academy would not be in the strong position it is today without her efforts.

Awardees, Washington Academy of Sciences Annual Meeting & Awards Banquet May 10, 2012 Arlington, Virginia

The Washington Academy of Sciences awarded **Vera Cooper Rubin** (left) with a Distinguished Career in Science award. Rubin is a Senior Fellow at the Department of Terrestrial Magnetism, Carnegie Institution of Washington. Also shown in the photo is award presenter **Sethanne Howard** of the Washington Academy of Sciences Board of Managers.

Behavioral Sciences and Social Sciences award recipient **Robert M. Groves** (right), Director of the U.S. Census Bureau. Shown with Groves is award presenter **Al Teich**, Research Professor of Science, Technology and International Affairs, George Washington University (filling in for Cora Marrett, Deputy Director of the National Science Foundation).

Biological Sciences award recipient **Jeeseong Hwang** (right), Research Biophysicist and Project Leader at the Radiation and Biomolecular Physics Division, National Institute of Standards and Technology (NIST). Shown with Hwang is award presenter **Kimberley Briggman** of NIST.

Engineering Sciences award recipient **Jeffrey E. Fernandez** (center), Managing Principal at JF Associates and **Mrs. Fernandez** shown with award presenter **Neal Schmeidler** of the Washington Academy of Sciences Board of Managers.

History of Science award recipient **Adrianne Noe** (left), Director of the National Museum of Health and Medicine shown with award presenter **Catherine With** of the Washington Academy of Sciences Board of Managers.

Lamberton Award for Elementary and Secondary Education awardee **Myra Lynn Koops Thayer** (right), Science Coordinator for Fairfax County Public Schools shown with award presenter **James Egenreider** of the Washington Academy of Sciences Board of Managers.

Mathematics and Computer Sciences awardee **Roderick J. Little** (right), Associate Director for Research & Methodology and Chief Scientist, U.S. Census Bureau shown with award presenter **Michael Cohen** of the Washington Academy of Sciences Board of Managers.

Mathematics and Computer Sciences award recipient **Geoffrey B. McFadden** (left), NIST Fellow. Shown presenting the award is **Charles Romine**, Director of the NIST Information Technology Laboratory.

Physical Sciences awardee **James K. Olthoff** (left), Deputy Director of the Physical Measurement Laboratory at the National Institute of Standards and Technology (NIST). Shown presenting the award is **Katharine Gebbie**, Director of the NIST Physics Laboratory.

Service to Science awardee **David S. Leckrone** (left), Senior Project Scientist for the Hubble Space Telescope Program (ret.), NASA. Shown with Leckrone is award presenter **Paul Arveson** of the Washington Academy of Sciences Board of Managers.

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5. References (and bibliography, if included) may be in the format generally acceptable for the disciplinary or professional field represented by the manuscript. They must be accurate, complete, and consistent in format throughout the paper. Use endnotes.
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Living Oceans Foundation

National Rural Electric Cooperative Association (NRECA)

Delegates to the Washington Academy of Sciences Representing Affiliated Scientific Societies

Acoustical Society of America	Paul Arveson
American/International Association of Dental Research	J. Terrell Hoffeld
American Association of Physics Teachers, Chesapeake Section	Frank R. Haig, S. J.
American Astronomical Society	Sethanne Howard
American Fisheries Society	Lee Benaka
American Institute of Aeronautics and Astronautics	David W. Brandt
American Institute of Mining, Metallurgy & Exploration	E. Lee Bray
American Meteorological Society	Vacant
American Nuclear Society	Charles Martin
American Phytopathological Society	Vacant
American Society for Cybernetics	Stuart Umpleby
American Society for Microbiology	Vacant
American Society of Civil Engineers	Vacant
American Society of Mechanical Engineers (ASME)	Daniel J. Vavrick
American Society of Plant Physiology	Mark Holland
Anthropological Society of Washington	Vacant
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Association for Women in Science	Jodi Wesemann
Association for Computing Machinery	Vacant
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(continued on back cover)

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(continued from previous page)

Institute of Electrical and Electronics Engineers, Washington DC Section	Richard Hill
Institute of Electrical and Electronics Engineers, Northern Virginia Section	Murty Polavarapu
Institute of Food Technologies	Vacant
Institute of Industrial Engineers	Neal F. Schmeidler
International Society of Automation	Vacant
Marine Technology Society	Vacant
Mathematical Association of America	Vacant
Medical Society of the District of Columbia	Vacant
National Capital Astronomers	Jay Miller
National Geographic Society	Vacant
Optical Society of America	Jim Cole
Pest Science Society of America	Vacant
Philosophical Society of Washington	Eugenie Mielczarek
Society of American Foresters	Daina Apple
Society of American Military Engineers	Vacant
Society of Experimental Biology and Medicine	Vacant
Society of Manufacturing Engineers	Vacant
Soil and Water Conservation Society	Terrell Erickson
Technology Transfer Society	Clifford Lanham
Virginia Native Plant Society, Potomac Chapter	Vacant
Washington Evolutionary Systems Society	Vacant
Washington History of Science Club	Albert G. Gluckman
Washington Chapter of the Institute for Operations Research and Management	Russell Wooten
Washington Paint Technology Group	Vacant
Washington Society of Engineers	Alvin Reiner
Washington Society for the History of Medicine	Vacant
Washington Statistical Society	Mike Cohen
World Future Society	Jim Honig

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The Journal of the Washington Academy of Sciences

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Editor's Comments

We are pleased to offer in this Fall issue of the *Journal* three papers and one guest editorial. The papers are eclectic, ranging from cognitive psychology to the environment of the Eastern Shore with a stop at management science, a benefit of an interdisciplinary journal such as ours. The editorial is a continuation of an interesting discussion begun at the Academy's Capital Science 2012 conference. Editorials offer our readers a chance to contribute to the discussion through Letters to the Editor.

The guest editorial by Lawrence Baines continues our CapSci discussion on modern-day communication. If we assume that that machines are becoming our basic units of communication, then we're experiencing a shift from words to sensations, which Baines feels has implications for more than just how we communicate. As noted, our *Journal* readers are encouraged to continue further the discussion.

In this issue, we also welcome a new faculty member to our author list. Dana Byrd recently finished her first year at her first academic position! She said she's excited about publishing in our Journal, and added, "What a great place to share research with a broader scientific community!" She has been – and wants to continue – studying the cognitive and brain differences in bilingual populations, as there's evidence they may be more cognitively-flexible. She also noted that the paper presented in this issue is a bit more of a cognitive psychology paper with some neuroscience explanation, rather than a neuroscience only paper.

The paper by Paul Arveson takes management science theory and overlays it onto the task of strategically managing scientific research organizations. This leads to a discussion of the performance measurement aspect of management, which continues to be a hot topic for scientific organizations. The exploratory and long-term nature of scientific research makes it difficult to identify discrete objective metrics. The article nicely links the social sciences (*e.g.* management science) with scientific theory and science policy.

My own contribution to this issue addresses a couple of topics I'm passionate about: the environment of the Eastern Shore/Chesapeake Bay area, and leveraging existing scientific and technical resources to improve our quality of life – that is, not only the environment, but also the economy … which is, by nature, another cross-disciplinary conversation! I

feel we can learn from other regional innovation clusters in this country (and around the world) and apply the lessons of ecosystem-based economic development to the Eastern Shore area.

Sally A. Rood, PhD
Editor, *Journal of the Washington Academy of Sciences*

Obituary for Dr. Arthur S. Jensen, P.E.

A life member of the Academy, Dr. Jensen passed away on September 25, 2012. He was 94 years of age.

Dr. Arthur S. Jensen was born in Trenton, NJ, 24 December 1917, and became an Eagle Scout in 1934 in Troop 20, of Greenwood Avenue Methodist Episcopal Church. Dr. Jensen was granted by the University of Pennsylvania the degrees of BS in Ed (physics) 1938, MS (physics) 1939 and PhD (physics) 1941. On 9 August 1941 he married Lillian Elizabeth "Betty" Reed, whom he fondly calls "Bess"; they had twin sons, Deane Ellsworth and Alan Forrest in 1942 and a daughter, Nancy Lorraine in 1959.

On 1 August 1941 he reported for active duty as a Naval Reserve Officer on the faculty of the US Naval Academy to teach physics and physics of aviation in the Department of Electrical Engineering until December 1945 with terminal leave until March 1946.

At RCA Laboratories, Princeton, NJ, as an Engineering Research Physicist Dr. Jensen invented the first practical, high-density, compact random access memory, the Radechon tube [which was used as binary digital memory in second generation computers, such as in the DEW-line radar and the first all electronic telephone central office, and as an analog image memory device in over-the-horizon radar and airborne moving target radar, the first applications of computer aided tomography (CAT scan using radar) to computer process image data to improve resolution]. For this he was elected Fellow in the Institute for Electrical and Electronic Engineers (IEEE).

After the war CAPT Jensen served as training officer in USNR Organized Surface Battalion 4-22 in Trenton, NJ, and later as commanding officer of Naval Reserve Research Company 5-4 in Baltimore, MD. With 22 years of satisfactory service he earned the American Defense Service Medal, American Campaign Medal, World War II Victory Medal, Naval Reserve Medal, and Armed Forces Reserve Medal, and retired in the U.S. Navy December 1977.

In 1957 Dr. Jensen was invited to establish the Special Electron Devices Laboratory at the Westinghouse Defense and Space Center in Baltimore, MD, where the Jensen family lived in the North Homeland community. From 1965 to retirement in 1994, Dr. Jensen served as a Consulting Physicist on the management staff. During this time Dr. Jensen

invented a high brightness display storage tube that was used for radar display in high altitude aircraft, an infrared camera tube that aided aerodynamic design of the SR71 aircraft, and low noise integrated circuits. He contributed to the Defense Meteorological Satellite and other reconnaissance programs.

In the 1960s at the instigation of Dr. Lyman Spitzer, Jr., who was at the time developing the concepts for the NASA Hubble Telescope, Dr. Jensen invented the Grating Storage Camera Tube (Westinghouse WX5074) which proved that long-exposure time analog visible-light photos could be taken electronically with multiple read-outs for transmission to a TV display. Dr. Jensen recalls a cold, February night watching Dr. Spitzer's team use this camera tube to take electronic photos of star fields at Princeton University's Observatory.

About 1973 Dr. Jensen was co-inventor with Dr. Harvey C. Nathanson, Westinghouse Research Labs, of the micromirror digital TV and movie projection system which was later developed and now manufactured by Texas Instruments for movie theaters – and, since 2003, manufactured by several companies as DLP-HDTV (digital light processing, high definition television) projection sets for home use.

Dr. Jensen's inventions resulted in 25 US patents, about sixty articles in physics and engineering journals and conferences, election to Life Fellow of the Institute of Electrical and Electronic Engineers (IEEE) and inclusion in Who's Who in America, Who's Who in Science and Technology, Who's Who in Aviation and Aerospace, and Who's Who in Engineering.

Dr. Jensen's lectures at universities in England and Germany resulted in his inclusion in the Dictionary of International Biography and the Royal Blue Book. His service as the electrical engineer on the Maryland State Board for Professional Engineers earned him the Maryland Governor's Citation and the Engineers' Council of Maryland's Outstanding Service Award in 1986. He is a life member of Sigma Xi, the American Physical Society, the American Association for the Advancement of Science, the American Legion, and the Military Officers Association of America.

In 2007 CAPT Jensen published a novel "Persian Gulf Jeopardy" of the fictional adventures of two women naval officers (the electronic department head and her mechanical section head) of the repair ship U.S.S. Vulcan which went to the rescue of the destroyer U.S.S. Stark

during the Iraq-Iran War, who on day shore liberty with other officers were kidnapped and had exciting adventures in the mountain valleys of southern Arabia.

Having met as fellow commuters on a train in 1939, he and his wife enjoyed traveling and adventure. Together they visited all seven continents, the Caribbean and Oceania including over fifty foreign countries in 21 of the 24 time zones, as well as visiting forty-nine of the United States, flying over the fiftieth, and visiting eight Canadian Provinces, tent camping in many of these in North America.

Their daughter, Nancy Lorraine Jensen, who received her degree in chemistry from the University of Maryland, College Park, and whom Goddard Space Flight Center (where she was an aerospace engineer/chemist) awarded its Exceptional Achievement Award for her bright nickel chemical coating for the pointing mirror of its weather satellite cameras – and which now get the cloud cover pictures used in TV weather broadcasts – died at age 35 in 1994. The following year Dr. and Mrs. Jensen endowed the Sons of Norway Foundation with the Nancy Lorraine Jensen Memorial Scholarship for young ladies who are studying chemistry, physics or mechanical, chemical or electrical engineering.

Their son, Alan Forrest, a First Class Scout and musician, was struck and killed by a car in 1956 at age 13. Their other twin son, Deane Ellsworth, an audio electronic engineer and entrepreneur who established and owned Jensen Transformers, Inc., with four buildings on Burbank Blvd., North Hollywood, CA (where he invented, designed and marketed the highest fidelity audio transformers), died at age 47 in 1989.

Dr. Jensen's marriage lasted for 63 happy years until 25 September 2004 when Bess died at age 82 of stroke and cancer in Art's arms while he sang love songs to her.

The foundation of Dr. Jensen's career was his training as an Eagle Scout with five palms, 48 merit badges and Vigil Honor in the Order of the Arrow. In return he served 25 years as an Assistant Scoutmaster, Explorer Advisor, Cubmaster and District Commissioner mostly in the George Washington Council, Princeton, NJ.

Guest Editorial

by

Lawrence A. Baines

The University of Oklahoma

Editor's Introduction: The Washington Academy of Sciences' Capital Science 2012 conference featured the panel session, "English as a Second Language: Analog Communication in a Digital World." At this session, there was no question that computer-mediated communication (CMC) -- everything from blogs to tweets – is contributing to the change and growth of language. Modern day communication often relies on context, acronyms, and variations in spelling, punctuation, syntax to avoid ambiguous meanings. Members of the panel and audience considered whether, in the long term, CMC will cause a seismic shift in how we speak and write. In short, they felt it's hard to tell at this point, and disagreed as to whether this is the "end of the analog world as we know it." They agreed, however, that it's interesting to speculate about the possibilities!

The guest editorial presented here is from the perspective that sociocultural changes may be coming so fast and furious that no one really understands the implications for self and society. "Sensations, Not Words" offers a snapshot of where we are now and explores where we might be headed. In the spirit of communication, we'd like to encourage follow-up letters from our readers on this topic.

Sensations, Not Words

THE WRITTEN WORD has served as an important mode of communication for thousands of years. The twenty-first century promises to deliver increasingly sophisticated, always-on machines that use sensory stimuli such as images and sound, not words, as basic units of communication. As people write and read less, while watching television and using telephones, computers, and other visual and aural electronic modes of communication more and more, reading books is ceasing to be the primary way of knowing something in our society. (Kernan, 1992, p. 140). This shift from words to sensations has implications for how we think, what we think, and how we feel about what we think. This essay describes the current state of the transition from words to sensations, and explores some potential gains and losses.

Imagine you are male, around 16-years-old, born into a middle class family. It is Saturday around 4:30 p.m. and you are at home, bored.

You have the vague sense that you have homework, but you do not feel particularly "in the mood" to do it. You want to have fun this Saturday afternoon, and do something that you want to do.

Like most adolescents today, you carry a phone and you have the choice of several hundred television stations, a small library of DVDs, and a TV set in your bedroom. Chances are that at least one additional large-screen television is located somewhere else in the house, as well as at least one computer with Internet access. (Rideout *et al*, 2010).

If your leisure time could be represented by 10 tokens and you had to distribute these 10 tokens across the activities you wanted to pursue over the weekend, the probable results would be as follows:

4 tokens = watching television
2 tokens = socializing and communicating
2 tokens = playing around on the computer
1 token = travel and other
1 token = playing sports or working out
0 tokens = reading

In actuality, this distribution of tokens mirrors the average time spent in leisure time activities by male and female students, aged 15-19, during 2011. Although time spent reading would not be sufficient to constitute a token, teens confessed to spending about 7 minutes per day reading, or about 1/10 of the time spent surfing on the computer and 1/23 of the time spent watching television. (Bureau of Labor Statistics (BLS), 2012).

Table 1. How teens, aged 15-19, spend their leisure time on weekends (daily averages) Source: BLS, 2012.

Activity / Tokens	Total leisure time	Watch TV	Socialize, communicate	Computer	Travel, other	Sports, work out	Relax, think	Read
Tokens	10	4	2	2	1	1	0	0
Hours	7.06	2.69	1.34	1.15	.81	.75	.20	.12
Mins	423.60	161.40	80.40	69.00	48.60	45.00	12.00	7.20

Although teens have less leisure time on weekdays, particularly if they are enrolled in high school or college, the percentage of time spent in various activities is roughly the same as on weekends. Time spent in either

reading or relaxing remains far short of the time necessary to warrant a token. The rarity of reading during the school week might seem surprising to those who assume that homework might still involve reading required texts outside of school hours. Apparently, reading is not a popular choice, even when homework is assigned. Indeed, a recent study of adolescents in a literature course found that most students read literary summaries on the Internet and took notes during discussions in class in lieu of actually reading the text. (Krieger, 2012). This quick and easy way of learning about a text, sometimes called "fake reading," has become *de rigueur* in high schools. (Lenters, 2006).

Obviously, for most of their leisure time, teens are not reading books, but are using electronic devices—television, the computer, or a phone—as a way of mediating experience. Playing around with electronic media provides instant gratification and an interactive experience, while reading a book requires both work and focus. While the outcome of the interaction with electronic media is fairly certain—some pleasing sounds and images, perhaps a message from a friend, the outcome of reading a book is anything but assured. With a book, interactions take place inside the head; with electronic media, interactions are externalized and dependent on the characteristics of the machine.

The Portable, Ubiquitous Brain

No device better represents the 21st century than today's handy, multi-use, smart phone. Carrying along a phone is like having a portable, powerful brain in your pocket. Even if you are sitting on a beach in California, within seconds, a phone can bring up images of ancient Chinese scrolls, translate a chunk of text from Urdu to English, remind you of an appointment, check the facts behind a recent political speech, and shoot and transport a photo instantaneously to the other side of the world. Magic.

On the college campus where I work, about half of the students on their way to class walk while gazing at their phones; the other half wear earbuds. Of course, one of the most popular uses for phones these days is texting, which can and does occur any time and any place. Texting always delivers the message, even if no one is on the receiving end. Although texts are, by nature, written comments, they share characteristics associated with the spontaneous and casual utterances of oral language. However, texts also carry a sense of urgency, and, when a text is received, real pressure exists to respond as quickly as humanly possible. A heavy

texter can appear to be perpetually staring at his/her phone, trying to avoid getting too far behind.

On average, adolescents send and receive more than 100 texts per day. (Nielsen, 2011). Of course, some people text more often, such as the high school student in Sacramento who recently sent and received over 300,000 texts in a single month, an average of 10,000 texts a day, or seven messages a minute. (*NBC Bay Area*, 2009).

The centrality of the phone to contemporary life is difficult to overstate. For most adolescents, the phone has become indispensable—it is the first thing they grab in the morning and the last thing that they touch before going to sleep at night. (*Time*, 2012, p. 34). Eighty-four percent of teens sleep with their phones within easy reach of their beds. (Lenhart *et al*, 2010).

In addition to keeping up with texts, emails, and voicemail, teens feel compelled to monitor their status and the status of their friends on social networking websites, such as Facebook. As it has been noted by self-proclaimed Cyborg Anthropologist Amber Case, students today must assiduously keep up with multiple identities—on social websites, for online gaming, with various virtual acquaintances, and also in school among peers, on a sports team, among friends, and within the family unit (Case, 2012). A disparaging post, especially within a public group can be damaging, and a few teens have had extreme responses to derogatory remarks, including withdrawal, retaliation, and suicide. (Robers *et al*, 2012).

Keeping up with multiple identities within manifold groups takes dedication and vigilance. The seemingly endless stream of news, gossip, and "urgent messages" is one of the reasons adolescents have stopped reading. Indeed, when queried about the lack of time devoted to reading books, most adolescents respond, "I just don't have the time." (Mullen, 2010).

When Faster is Not Fast Enough

Certainly, a distinguishing feature of contemporary life is its sheer speed. The time span that most humans consider an intolerable waiting period continues to shorten. A laptop computer that takes more than ten seconds to boot up seems antiquated; webpage that takes more than four seconds to load is unbearable. (ACM, 2007, p. 9).

Indeed, to wade through the information deluge at any moment in time, to keep up with trends through Twitter and Pinterest; to read the news on various websites; to peruse the most recent journals, magazines, or books (300,000 new books or editions are published every year in the United States); could take untold hours. Thus, multi-tasking has become a necessary and expected way for humans to keep up. When watching TV, for example, most viewers also operate at least one other device, such as a phone, tablet, or laptop computer. (Nielsen, 2012).

James Gleick terms the obsession with speed, "hurry sickness," and classifies it as a kind of psychosis.

> We—those of us in the faster cities and faster societies and faster mass culture of the technocratic dawn of the third millennium C.E.—are manic. The symptoms of mania are all too familiar: volubility and fast speech; restlessness and decreased need for sleep; heightened motor activity and increased self-confidence. (Gleick, 1999, p. 36).

Unfortunately, one of the casualties of an always-on lifestyle is that little time remains at the end of the day to sit back and think—about what is important, what is superfluous, and what is worth pursuing. Quiet moments of reflection that have traditionally accompanied reading seem fewer and far between. George Steiner notes, "there is a fierce privacy to print and claim on silence ... the traits of sensibility now most suspect." (Steiner, 1984, p. 435). Recall from Table 1 that adolescents spend only 12 minutes per day thinking and relaxing. Apparently, most teens must "hurry up and relax" if they are going to relax at all.

Although technology can improve efficiency and speed, it is not a panacea for all problems. Yet, the belief that any field can achieve economies of scale with the proper application of technology and a concomitant reduction in costs has become widespread. Educational reformers compress four years of teacher preparation into five weeks (Teach for America), the formerly fifth grade math curriculum wends its way into the third grade (Common Core Curriculum), and the senior year of high school becomes the ideal time for taking college-credit courses.

It has become blasphemous to suggest the possibility that certain endeavors cannot be accelerated. Are there really short-cuts for becoming a world class violinist, qualifying for the Olympics in the 10,000 meter run, performing heart surgery, or teaching 30 rambunctious six-year-olds?

Indeed, many endeavors, by their very nature, require years of practice, unwavering discipline, and a laser-like, intensive focus.

Yet, these time-consuming, energy-depleting habits—practice, discipline, focus—are precisely the habits that the electronic media does not encourage. Electronic media offer quick, sensory joyrides; endless distractions; and the ability to log on or shut off whenever and wherever you feel like it. Unquestionably, a tension exists between the time necessary for "slow-build" endeavors, such as building expertise and frenetic "fastpitch" endeavors, such as making the rounds in chatroulette. (chatroulette.com).

In a hurry-up world, there may be little time to reflect, so decisions have to be made spontaneously, in the heat of the moment. To understand how decisions are made under pressure, research on speed-dating can help. In a speed-dating situation, participants gather in a room, then half sit at a table (usually the women), while the other half (usually the men) move from table to table every few minutes. A commercial website known as "slow dating" offers the following rationale for extending the time for actual conversation to a whopping four minutes:

> We feel that three minutes is too short a time with all the moving between tables and the note taking. We strongly believe that four minutes is the right amount of time to decide whether you're prepared to invest more time in follow up emails and phone calls to land a real date with someone you meet at one of our events. Four minutes per date also enables you to meet 15-20 dates in one night without getting completely worn out. (Slow dating, 2012).

In speed-dating situations, even under conditions that promise a full extra minute of interaction, most participants make up their minds about the other party within the first seconds of contact. That is, most participants make the decision to "like" or "dislike" instantaneously, without regard to what the other person might actually say or do during the conversation. (Houser *et al*, 2008).

When stakes are high and decisions must be immediate, stress increases. A human being under stress, such as a person under attack by a grizzly bear (at a national park or at a speed-dating event), may not have time to think rationally. In most cases, stress invokes a "fight or flight" reaction.

The Social Milieu of Words

In a hurry-up, high-stress world, words become, as William Burroughs suggested, "an oxcart way of doing things, awkward instruments." (Burroughs, 1965). The challenge from the grizzly bear evokes a scream, not an eloquent proclamation.

The form factor of the portable ubiquitous brain (phone), with its tiny keys and small display makes images and abbreviations much more practical than long passages of pure grammatically-correct text. Few individuals are going to type a precise polysyllabic word when an emoticon or short word with approximate meaning will suffice. As the functions of phones become integrated into clothing and eyewear (a contact lens that connects with the Internet has already been developed), language will become ever more simplified.

Using emoticons and Internet acronyms slow the wear and tear on thumb muscles (from typing too much) and can still manage to communicate the gist of a message.

> ***Example:*** u found digs (°□°). imho r e good $. hope u not nifoc. lol. Ttfn.
>
> ***Translation:*** You found a new home? I am so happy for you. In my humble opinion, real estate is an excellent value in today's market. I just hope that you are not naked in front of the computer right now. Oh, I am just trying to be funny (laugh out loud). Let's talk to each other again soon (ta-ta for now).

The condensed simplistic plainspeak of txtg (texting) aligns well with the language of other electronic media. Scripts for television shows and films are imagined transcriptions of conversations, and are written to mimic human speech, which means the inclusion of inflections (like), short words (hey), and simple sentences (Run for your life!). The more complex language found in the exposition of books gets left behind when content gets adapted for electronic media. (Baines, 1996).

Websites are dominated by images and plainspeak for many reasons—to insure readability among visitors of all ages and reading levels, to make comprehension easier for international visitors (or translating machines), and to avoid alienating the multitudes, who by-and-large shun text-heavy websites. (Leach, 2011). Most adolescents use the Internet to view videos or images, play games, go shopping, or visit/update their webpages. (J. Nielsen, 2012). It is a rare event when an adolescent goes online to download and read one of the millions of free e-

books available through Gutenberg.org, Bartleby.com, or other book-related sites.

So, in re-examining the activities from Table 1, there seems to be no time, save the few minutes spent relaxing or reading, when an adolescent might possibly encounter an unfamiliar word.

Yet, literacy researchers insist that knowledge of words is most often acquired informally, outside of school, principally through voluntary reading. (Mason *et al*, 1991, p. 728). Free reading has been shown to be the most accurate predictor of vocabulary growth in school-age children. (Fielding *et al*, 1986). Encountering an unfamiliar word while free reading does not mean that a student will automatically comprehend it, though foggy notions about the meanings of words eventually lead to more complete knowledge. (Nagy *et al*, 1985, 1987b). It turns out that having partial knowledge of a word is advantageous–an essential step in increasing one's vocabulary. (Stanovich, 1991).

Although a student might have a 5-10% chance of learning the meaning of any particular word from context, an encounter with 20,000 unfamiliar words translates into an increased vocabulary of up to 2,000 words. (Nagy, 1988, p. 30). In recent years, it has been estimated that school-age children's vocabularies increase at the rate of approximately 3,000 words a year, until they reach their mid-teens. (Nagy & Herman, 1987; Miller & Gildea, 1987).

However, if reading continues to falter as a leisure time activity, the amount of words that students will know seems likely to fall. Books are the repositories of language, and if students stop reading books, where will they encounter new words?

Words and the Intellect

About the importance of language, Swiss linguist Ferdinand de Saussure wrote, "Without language, thought is a vague, uncharted nebula. There are no pre-existing ideas and nothing is distinct before the appearance of language." (DeSaussure, 1974, p. 112). Certainly, words are tools for organizing experience, interpreting sensory perceptions, and giving meaning to life events. Typically, a person's knowledge of words corresponds with the measure of his/her general intelligence. Although one cannot determine the causal complexities in the relationships among reading comprehension, intelligence, and vocabulary knowledge with unequivocal precision, the preponderance of research suggests a strong

correlation. To be sure, "the relationship between vocabulary and general intelligence is one of the most robust findings in the history of intelligence-testing." (Beck *et al*, 1987, p. 147).

In a study involving more than 100,000 students from fifteen different countries, the median correlations between a student's knowledge of vocabulary and reading performance ranged from .66 (18-year-olds) to .75 (14-year-olds). (Thorndike & Lorge, 1972). Other research has found that students with extensive vocabularies also seem to possess an impressive semantic understanding of the connections among words, an understanding that further aids in reading comprehension. (Baker & Brown, 1984).

When students fail in school, it usually has more to do with their lack of exposure to words and their inability to comprehend on-grade-level texts than other factors, such as behavior, socio-economic status, or family background. (Heath, 1982, 1983; Hart & Risley, 1995). Literacy researchers Healy and Barr write,

> The use of one's own words as one is learning subject matter relieves the abstract nature of school knowledge, causing reverberations and establishing resonances between what is to be learned and what is already known. When students of any background must foreshorten this natural process, which they have used since birth to make sense of their experiences, their achievement suffers. (Healy & Barr, 1991, p. 825).

Robert Marzano discerns three relationships between words and thoughts:

1) Words are a form of thought,
2) Words are mediators of thought, and
3) Words are tools for enhancing thought.

According to Marzano, *Words as a form of thought* means that language acts as the root of human cognition, supplementing and synthesizing linguistic and nonlinguistic codes over time. *Words as mediators of thought* has to do with the self-talk (or covert talk) that a person uses to clarify and control his or her own thinking. Finally, because spoken and written words are the very basic tools of learning, *words enhance thought*. In Marzano's formulation, a person with low vocabulary knowledge may find it difficult to understand a text, and difficulties may

be exacerbated by limitations in thinking and the inability to self-reflect. (Marzano, 1991, p. 563).

At the least, having a meager knowledge of words may be a warning of sorts, as it is demonstrated by the fact that 60% of prisoners, 75% of welfare recipients, and 85% of unwed mothers can be classified as poor or dysfunctional readers. (NCES, 2009; IRA 2012). Obviously, a lack of word knowledge does not necessarily lead to a life of crime, unemployment, and sex at an early age, but poor reading and writing skills are serious impediments to academic success at all levels. (Radunzel & Noble, 2012).

Towards an Electronically-Mediated Oral and Visual Culture

The current fashion is to insert voice recognition capabilities into more and more machines. Today, the driver of a car can change the radio station by simply telling the car to choose another station; a son can speak to his mother by telling his phone, "Call mom;" a journalist can record and transcribe an interview in real time with the help of a computer.

In his book *Orality and Literacy*, Walter Ong makes the claim that the structure of the brain, itself, is dependent upon how much a person reads and writes in comparison with how much a person listens and speaks. The languages of oral cultures, for example, typically contain less than five thousand words, while chirographic cultures (those based upon a written alphabet) typically contain hundreds of thousands of words. For example, there exist over a million and a half words in print in English. (Ong, 1982, p. 107).

The ability to capture thought into succinct written language, according to Ong, provided the impetus for the development of modern science. (Ong, 1982, p. 114). That is, the sophisticated tools of language made possible the expression of complex thoughts, ideas, and intuitions, which otherwise would have gone unrecorded. Words in an oral culture are fewer and the meanings may be less precise. In an oral culture, one word may serve many functions. For example, a single word might signify all objects that fly-be it a mosquito, bird, airplane, rocket, or pilot. (Whorf, 1974).

In an oral culture, communication is often done in the presence of the group. At a fundamental level, oral culture relies upon sound, image, and the immediacy of the group experience, while a chirographic culture is built upon the written word and individual experience.

From this perspective, the popularity of social networking sites that are predicated on an ongoing group experience, such as Facebook, could be construed as a sign of a shift towards an oral society. The one-dimensional unifying themes and crowdsourcing on display at recent political conventions also highlight the tendency towards groupthink and the valorization of perception over rational thought. Although most societies represent a blend of the oral and chirographic, lately, the United States seems to be moving its chirographic culture to the cloud so it can free up more space to experience the now of electronically-mediated information.

Words and Biology

Although Walter Ong was a professor of English literature and philosopher, his theories have been confirmed by neuroscientists who measure physical changes and blood flow differentials in the brain through various technologies, such as Positron Emission Tomography (PET). In a recent experiment, pictures of the brains of a group of struggling readers were taken as part of a pretest. Then, the struggling readers were given 100 hours of intensive, "word therapy" to help them improve their reading comprehension. After 100 hours of word therapy, pictures of the struggling readers' brains revealed that, as their reading comprehension improved, their brains physically changed.

Lev Vygotsky, the Russian educator who died in 1934, postulated that words were crucial to the cognitive development of children to such an extent that they could influence behavior in nonlinguistic, as well as linguistic, ways. The final sentence of Vygotsky's book *Mind in Society* declares that "a word is a microcosm of human consciousness." (Vygotsky, 1978).

Since the 1980s, Yale University Psychiatrist Ralph Hoffman has adapted aspects of Vygotsky's theories to explore the causes of schizophrenia. (Hoffman, 1986a, 1986b, 1986c, 1991, 2012). One of Hoffman's major breakthroughs has been the hypothesis that verbal hallucinations or "voices" heard by schizophrenics may result from the inability to regulate their own discourse plans. Consequently, the voices that schizophrenics hear may be ideas that have somehow wandered off from their conscious brains.

Through Hoffman's version of "word therapy," a program that teaches schizophrenics to gain control over ideas and their overt expression, verbal hallucinations have been almost totally eradicated.

Thus, from two different perspectives, Vygotsky and Hoffman demonstrate the power of words to not only capture thoughts, but to direct thoughts as well.

When she encounters words, Temple Grandin, the renowned equipment designer for the livestock industry, translates "both spoken and written words into full-color movies, complete with sound, which run like a VCR tape in my head." (Grandin, 2006a). Grandin, who is autistic, is able to visualize complete facilities for animals without invoking words. (Grandin, 2006b). However, when communicating her ideas to others, Grandin still must translate the images in her head into words. That she has written ten books would seem strong evidence that, even in the mind of an image-dominated savant like Temple Grandin, words play a critical role.

Goldfish in a Bowl

Conjecture concerning how a transformation from words to sensations will affect how we think and live is necessarily speculative. E.M. Forster has said that "it is a mistake to think that books have come to stay. The human race did without them for thousands of years and may decide to do without them again." (Forster cited in Plimpton, 1990, p. 351).

However, from the time of the pre-Socratic societies of Greece to the bounty on the head of Salman Rushdie, and every war and love affair in between, the degree to which words can empower or incapacitate has depended upon the linguistic dexterity of the user. Alfred North Whitehead has suggested that language was the primary force in the creation of the soul – "The mentality of mankind and the language of mankind created each other. The account of the sixth day should be written, 'He gave them speech, and they became souls.'" (Shrodes *et al*, 1974, p. 76).

Ernst Cassirer, in his studies of language and mythology, often wrote about the sacrosanct quality of words. "There must be some particular, essentially unchanging function that endows the Word with this extraordinary, religious character, and exalts it *ab initio* to the religious sphere, the sphere of the 'holy.' In the creation accounts of almost all great cultural religions, the Word appears in league with the highest Lord of creation; either as the tool which he employs or actually as the primary source from which He, like all other Being and order of Being, is derived." (Cassirer, 1925, pp. 45-46).

The medium is not only the message as Marshall MacLuhan alleged, but the propensities and constraints of media affect both the content of the message and how the message will be received. Every new medium—cars, railroads, computers, telephones, electric lights—reorganizes our consciousness, but like goldfish in a bowl, we remain unaware of the transformation.

In a culture biased towards image and sound, in a culture that has little need for words to symbolically represent social reality, the possibility exists that an individual may not possess the resources with which to express what is in the mind. If that possibility is indeed a reality, then, as the corpus of language shrinks, so shrinks human capacity for intelligent thought. One wonders what can exist in the mind to express without the language with which to express it.

In the book *Crisis of Our Age*, Pitirim Sorokin contends that ours is an age obsessed with the sensate–the pursuit of wealth, pleasure, and leisure, at the expense of social responsibility, virtue, and truth. For humans enraptured by the sensate, only the present moment is real and desirable; consequently the impulse is to "snatch the present kiss; get rich quick; seize the power, popularity, fame, and opportunity of the moment." (Sorokin, 1943, p. 97).

Electronic media offer an endless array of sensuous experiences and they offer them right here, right now, and without strings—no need to decode text, or even, to think rationally. Today it is possible to spend more time in the vicarious realms of electronic media than in the "real world." Many people do.

In twenty-first century society, electronic media, not religion, serves as the "*opium des volkes*." (Marx, 1843). It is not a religious artifact, but the big-screen television that has become the dominant artifact in contemporary homes. Adolescents do not carry around pocket-size religious texts; they carry phones.

It is well known that Plato wanted to banish the poets from his Republic. Eric Havelock in his book *Preface to Plato* explains why. During the time in which Plato lived, poets roamed from town to town, telling long, elaborate tales from memory in front of large crowds.

Plato did not want the poets in his Republic because he thought his fellow citizens should think for themselves. The rambling poets of Ancient Greek times were not renowned thinkers. They recited; they pandered; they performed. Havelock writes that ancient Greek poetry, "far from

disclosing the true relations of things or the true definitions of the moral virtues, forms a kind of refracting screen which disguises and distorts reality and at the same time distracts us and plays tricks with us by appealing to the shallowest of our sensibilities." (Havelock, 1963, p. 26).

Havelock's message about the threats posed by distraction, distortion, and superficiality seems prescient. The problem is that many of us are reticent to read such a challenging text. We may lack either the vocabulary to understand it or the time to read and reflect on it. An easier course of action would be to wait for the film adaptation and maybe order it through Netflix.

References

Association for Computing Machinery (2007, January). Four second warning. *Communications of the ACM 50*(1).

Cassirer, E. (1925). *Sprache und Mythos: Ein Beitrag zum Problem der Götternamen*. Leipzig, Germany: B. G. Teubner. English Translation by Susanne Langer: *Language and Myth*. 1946. New York and London: Harpers & Brothers. (Edition consulted: Unabridged and unaltered republication by Dover Publications, 1953, pp. 45-46).

Baines, L. (1996). From page to screen. *Journal of adolescent and adult literacy 39*(8): 612-622.

Baker, L. & Brown, A. (1984). Metacognitive skills and reading. In P. Pearson, R. Barr, M. Karmi l, & P. Mosenthal (Eds.), *Handbook of reading research* (pp. 353-394). White Plains, NY: Longman.

Beck, I., McKeown, M. & Omanson, R. (1987). The effects and uses of diverse vocabulary instructional techniques. In M. McKeown & M. Curtis (Eds.), *The nature of vocabulary acquisition* (pp. 147-163). Hillsdale, NJ: Erlbaum.

Bureau of Labor Statistics (2012). *American time use survey*. Retrieved from www.bls.gov/tus.

Bureau of Labor Statistics (2012). *Table 11: Time spent in leisure and sports activities for the civilian population by selected characteristics, 2011 annual averages.* Retrieved from www.bls.gov/news.release/atus.t11.htm.

Burroughs, W. (1965). The Art of Fiction No. 36. Interview by Conrad Knickerbocker. *The Paris Review, 35*, Fall 1965, pp. 13-45.

Case, A. (2012). *Cyborg anthropology*. Retrieved from http://caseorganic.com/blog/

DeSaussure, F. (1974). *Course in general linguistics*. New York, N.Y.: McGraw Hill.

Fielding, L., Wilson, P. & Anderson, R. (1986). A new focus on free reading: The role of trade books in reading instruction. In T. Raphael (Ed.), *The contexts of school-based literacy* (pp. 149-160). New York, N.Y.: Random House.

Forster, E., cited in Plimpton, G. (1990). *The writer's chapbook*, New York: Viking.

Gleick, J. (1999) *Faster*. New York, N.Y.: Pantheon.

Grandin, T. (2006). *Thinking in pictures*. Retrieved from www.grandin.com/incvisual.thinking.html

Grandin, T. (2006). *Animals in translation*. New York, N.Y.: Mariner Books.

Hart, B. & Risley, T. (1995). *Meaningful differences in the everyday experience of young American children*. Baltimore: Brookes Publishing.

Healy, M. & Barr, M. (1991). Language across the curriculum. In J. Flood, J. Jensen, D. Lapp & J. Squire (Eds.), *Handbook of research on teaching the English language arts* (pp. 820-825). New York, N.Y.: MacMillan, p. 825.

Heath, S. (1982). What no bedtime story means: Narrative skills at school and home. *Language in society, 11*, 49-75.

Heath, S. (1983). *Ways with words*. Cambridge: Cambridge University Press.

Hoffman, R. (1986a, September). What can schizophrenic "voices" tell us? *Behavior and Brain 9*(3), 535-548.

Hoffman, R. (1986b, September). Verbal hallucinations and language production processes in schizophrenia. *Behavioral and Brain 9*(3), 503-517.

Hoffman, R. (1986c, September). A comparative study of manic vs. schizophrenic speech disorganization. *Archives of General Psychiatry 43*(9), 831-838.

Hoffman, R. (1991, November-December). The Duphar lecture: On the etiology of alien, nonself attributes of schizophrenic "voices." *Psychopathology 24*(6), 347-355.

Hoffman, R. (2012). *Yale medical group*. Retrieved from www.yalemedicalgroup.org.

Houser, M., Horan, S. & Furler, L. (2008). Dating in the fast lane. *Journal of social and personal relationships 25*(5), 749-768.

International Reading Association (2012). *Literacy facts*. Retrieved from www.reading.org/downloads/meetings/ILD2007_literacy-facts.pdf.

Kernan, A. (1992). *The Death of Literature*. New Haven, CT: Yale University Press.

Krieger, C. (2012). *What strategies do resistive readers use to fake their way through school assigned texts*? (Unpublished doctoral dissertation). The University of Oklahoma, Norman, Oklahoma.

Leach, A. (2011, March 20). *Website redesign: A design for strife*. The Independent. Retrieved from http://www.independent.co.uk/life-style/gadgets-and-tech/features/website-redesign-a-design-for-strife-2248852.html.

Lenhart, A., Ling, R., Campbell, S. & Purcell, K. (2010). *Sleeping with the phone on or near the bed*. Retrieved from http://www.pewinternet.org/Reports/2010/Teens-and-Mobile-Phones/Chapter-3/Sleeping-with-the-phone-on-or-near-the-bed.aspx

Lenters, K. (2006). Resistance, struggle, and the adolescent reader. *Journal of Adolescent & Adult Literacy, 50*(2), 136-146.

Marx, K. (1843). *A contribution to the critique of Hegel's Philosophy of Right*. Retrieved from http://www.marxists.org/archive/marx/works/1843/critique-hpr/intro.htm.

Marzano, R. (1991). Language, the language arts and the teaching of thinking. In J. Flood, J. Jensen, D. Lapp & J. Squire (Eds.), *Handbook of research in teaching the English language arts* (pp. 559-586). New York, N.Y.: MacMillan.

Mason, J., Herman, P. & Au, K. (1991). Children's developing knowledge of words. In Flood, J., Jensen, J., Lapp, D. & Squire, J. (Eds.) *Handbook of research on teaching the English language arts* (pp. 721-731). New York, N.Y.: MacMillan.

Miller, G. & Gildea, P. (1987). How children learn words. *Scientific American 257*(3), 94-99.

Mullan, K. (2010). Families that read: A time-diary analysis of young people's and parents' reading. *Journal of research in reading, 33*(4), 414-430.

Nagy, W. (1988). *Teaching vocabulary to improve reading comprehension*. Urbana, IL: NCTE.

Nagy, W. & Herman, P. (1987a). Breadth and depth of vocabulary knowledge: Implications for acquisition and instruction. In M. McKeown & M. Curtis (Eds.) *The nature of vocabulary acquisition*. Hillsdale, NJ: Erlbaum.

Nagy, W., Anderson, R. & Herman, P. (1987b). Learning word meanings from context during normal reading. *American Educational Research Journal 24*, 237-270.

Nagy, W., Herman, P. & Anderson, R. (1985). Learning words from context. *Reading research quarterly 20*, 233-253.

National Center for Education Statistics (2009). *Basic reading skills and the literacy of the America's least literate adults*. Washington D.C.: Institute of Education Statistics.

NBC Bay Area (2009, May 5). *Teen texts 300,000 times in month*. Retrieved from www.nbcbayarea.com/newsbusiness/Teen-Texts-300000-Times-In-Month.html.

Nielsen (2011). *The mobile media report: State of the media*. Retrieved from http://www.nielsen.com/us/en/insights/reports-downloads/2011/state-of-the-media--mobile-media-report-q3-2011.html

Nielsen (2012). *State of the media: U.S. Digital Consumer Report*. Retrieved from http://www.nielsen.com/us/en/insights/reports-downloads/2012/us-digital-consumer-report.html

Nielsen, J. (2012). *Writing for the web*. Retrieved from www.useit.com/papers/webwriting.

Ong, W. (1982). *Orality and literacy*. New Haven, CT: Yale University Press.

Radunzel, J. & Noble, J. (2012). *High school graduates: College readiness, enrollment, and long-term success*. Iowa City, IA: ACT.

Rideout, V., Foehr, U. & Roberts, D. (2010). *Generation M2*. Washington, D.C.: Kaiser Family Foundation.

Robers, S., Truman, J. & Zhang, J. (2012). *Indicators of school crime and safety: 2011*. Washington, D.C.: U.S. Department of Education.

Slow dating (2012). *Is four minutes per date long enough?* Retrieved from http://www.slowdating.com/faq.aspx

Sorokin, P. (1943). *Crisis of our age*. New York, N.Y.: Dutton.

Stanovich, K. (1991). Word recognition: Changing perspectives. In Barr, R., Kamil, M., Mosenthal, P. & Pearson, P. (Eds.) *Handbook of reading research* (pp. 418-452). New York: Longman.

Steiner, G. (1984). *George Steiner: A reader*. New York, N.Y.: Penguin.

Thorndike, E. & Lorge, I. (1972). *The teacher's word book of words*. New York, N.Y.: Teachers College Press.

Time (2012, August 27). How has wireless technology changed how you live your life? p. 34.

Whitehead, A. (1974). Modes of thought. In C. Shrodes, H. Finestone & M. Shugrue (Eds.), *The Conscious Reader*, New York, N.Y.: MacMillan.

Whorf, B. (1974). *Language, thought and reality.* Cambridge, MA: M.I.T. Press.

Vygotsky, L (1978). *Mind in society*. Boston, MA: Harvard Press.

Bio

Lawrence Baines serves as chair of Instructional Leadership and Academic Curriculum at The University of Oklahoma. Previously, he has held positions as The Judith Daso Herb Endowed Chair at University of Toledo and The G. Leland Green Endowed Chair at Berry College (Georgia). His webpage is www.lawrencebaines.com.

Cognitive Benefits of Being Bilingual

Dana Byrd

Texas A & M University at Kingsville

Abstract

Most language research has focused on monolingual speakers. However, bilingualism/multilingualism is far from unusual. Recent studies reveal that 50% of the world is multilingual and about 20% of households in the U.S. speak more than one language, with the majority using Spanish. Previously, researchers perceived bilingualism as a burden rather than a benefit, especially in children. The burden involves having to learn multiple vocabularies, grammars, and nuances, creating a potential for a smaller vocabulary and weaker associations between actual words and their meaning, as reflected in slower response in naming objects. However, under the right circumstances, many bilinguals are fully functional in both languages, so deficits are not necessarily permanent or profound. In fact, evidence indicates that bilinguals not only have differences in non-language thinking and brain functioning from monolinguals, but also benefits over monolinguals. Research suggests that being bilingual has an effect if both languages are presented from an early age, changing the way bilinguals process and react to information. Being bilingual in childhood seems to accelerate complex cognitive processing. While this advantage appears less marked during the peak of cognitive ability (young adulthood), underlying changes in cognitive abilities and neurological structure carry forward into older adulthood, slowing cognitive decline. Interesting questions remain about the nature of the bilingualism and how it plays a role in generating benefits.

Introduction

THE DEVELOPMENT AND USE of language is arguably the most important characteristic that separates humans from other species. To date, however, most language research has focused on monolingual subjects, in spite of the fact that bilingualism/multilingualism in today's world is far from unusual. Recent studies have revealed that 50% of the world is multilingual (Grosjean, 2010), and that approximately 20% of households in the United States speak more than one language, with the majority of U.S. bilingual speakers using Spanish (Shin & Kominshi, 2010).

But how do bilinguals manage the different languages that they use? How is it that they select one language to use in one setting and then switch to another in another language in another context? How do they switch from one language to the other casually as they converse with a fellow bilingual? These questions all boil down to the question of how

bilinguals store, activate, and produce their languages. By extension, how has becoming bilingual/multilingual affected the development of their overall development of the mind? In recent years, knowledge about how our minds work has expanded greatly as the result of improved research techniques. Advances in verbal and nonverbal assessments provide much more specific information about cognitive development in areas of interest. Similarly neuroscientific research of the mind has been greatly enhanced through electroencephalographic (EEG) and functional magnetic resonance imaging (fMRI) studies. Together these research approaches have yielded important information about the cognitive and linguistic development of bilingual speakers.

"Activation" of Listening and Production in More Than One Language

It may not seem surprising that bilinguals, when spoken to, are *listening* for words in both languages, making themselves "open" to receiving information in either language. What is surprising, however, is that there is evidence that both languages are activated for *language production* at the same time, even for production of just a single word (Martin, Dering, Thomas, & Thierry, 2009). The convention for labeling a speaker's first, often stronger language is "L1," whereas the speaker's second language is labeled "L2." Hatzidaki, Branigan and Pickering (2011) reported that the degree of activation is stronger in the more dominant language (typically L1). Bilinguals may also be activating both grammar systems when generating language in an interchange, or at least when they are switching back and forth between the two languages (Hatzidaki, Branigan, & Pickering, 2011), as some bilinguals do automatically when interacting with their bilingual peers (Gollan & Ferreira, 2009).

How do bilinguals handle this dual activation of languages? With this dual activation there may be largely unconscious, though in some cases conscious cognitive control that allows selection. This control may be activation of one language or inhibition of the other, or even the controlled alternating activation and inhibition upon switching back and forth between languages when speaking with someone who is equally bilingual (Kroll, Bobb, Misra, & Guo, 2008). This ability to switch between languages with such ease has been demonstrated through functional Magnetic Resonance Imaging, or fMRI, a measure of the blood flow in the brain during certain tasks. These images show that in

bilinguals the areas of the brain used for each of the two languages are the same (Wang, Xue, Chen, Xue, & Dong, 2007).

The Burdens of Being Bilingual

In past decades, and perhaps even today, researchers have perceived bilingualism as a burden rather than a benefit, especially in children. The burden involves having to learn multiple vocabularies, grammars, and even cultural nuances. As a result, there is the potential for a smaller vocabulary (Bialystok & Luk, 2011, Bialystok, Luk, Peets, & Yang, 2010) and "weaker links" or associations between actual words and meaning they represent, resulting in slower object naming (Bialystok, Craik, Green, & Gollan, 2009). Depending on their circumstances, many bilinguals are fully functional in both languages. Clearly, these deficits are not permanent or profound. Bilingualism, if so common that half the world population is bilingual, is not an abnormal state of brain development. In fact, there is a long-standing body of evidence that bilinguals have differences in their non-language thinking and brain functioning that show not only variation from monolinguals, but also *benefits over monolinguals.*

The Benefits of Being Bilingual

The benefits of bilingualism can appear as early as infancy, resulting in an improved early ability to form categories and interpersonal associations. Infants exposed to bilingual environments begin to use acoustic information to distinguish their two languages, a step toward understanding that there are cognitive categories that must be distinguished. Once past the pre-lingual state of development, young children being raised in bilingual environments learn to use the language appropriate to the person to whom they are speaking. Such accommodation to individual speakers may be the result of simple trial-and-error learning. In other words, young bilingual children learn that if they correctly match the language with their conversational partner, they get positive results, but if they mismatch the language to the person, they get no results. Therefore, for early bilingual language learners, this learning is the beginning of understanding interpersonal association and context not yet acquired by their monolingual peers (Werker & Byers-Heinlein, 2008). Putting it differently, early bilingual language learners may have an advantage over monolinguals in understanding others' states of mind. These preschoolers show evidence that they know that certain people will understand certain languages. This cognitive ability to

understand that there are differences in others' understanding is referred to as "Theory of Mind."

Theory of Mind

Emergence of Theory of Mind (ToM) is a major milestone for a preschooler: realizing that other persons can think, and that these other people think *differently* than the child does. For example, a young child without ToM might stand directly in front of the TV thinking, "I can see the TV, so everyone else in the house can see the TV too." A child achieves a more sophisticated state of Theory of Mind upon realizing that someone else can not only think differently than the child about the world, but that the other person may hold a false belief.

This point can be illustrated using a standard ToM assessment. A preschool child is shown a box labeled for crayons and asked what he thinks is inside. The child predictably answers, "crayons." Next the child is shown that the box contains ribbons. A new person whom the child has never met comes into the room and the experimenter asks the child to name what the new person think is in the box. If the child answers "crayons," he has achieved ToM. The preschooler recognizes that the new person has a state of mind different than his own, and that the new person will reach the same conclusion about the crayon box that the child did in the past: that it contains crayons. If the child has not achieved ToM, he will think that the new person must share the same "state of mind" or knowledge as the child. In this situation, the child will reply that the box contains ribbons.

How do Monolingual and Bilingual Preschoolers Compare in the Acquisition of ToM?

Young monolingual preschoolers, about 3 years of age, usually fail ToM tests such as the one described above, whereas older preschoolers, about 5 years of age, pass this test. When younger preschoolers, just on the cusp of understanding ToM, are given the test an interesting difference is seen between monolingual and bilingual children. When presented this false belief task, a greater number of younger bilingual preschoolers than monolinguals passed the test demonstrating ToM, even when age and verbal ability were taken into account (Farhadian, Abdullah, Mansor, Redzuan, Gazanizadand, & Kumar, 2010). This false belief task was even tested to see whether a language advantage would further improve their ToM performance. Bilingual children were presented a version of the task in which the new person entering the room spoke a different language than

the person who knew the truth about the box of crayons. The same advantage was found in the bilingual children regardless of the language in which the stimuli were presented. So, younger bilingual preschool children can understand about other's thinking earlier and in a more sophisticated way than monolingual children. It was an advantage independent of language (Kovács, 2009).

The study above, which controls for verbal ability, suggests that the child's more sophisticated ToM skills are not solely the result of more sophisticated verbal skills. But are these bilingual children also able to perform in a more advanced way than monolinguals on nonverbal tasks? Are their increased abilities more global, that is, beyond using language to enable their reasoning? One way to answer these questions, other than giving language-based tests and controlling for language, is to use non-verbal tests. Do bilingual preschoolers still excel beyond monolingual preschoolers on those tasks? It appears that on certain tasks, but not all, the answer is *yes*. Preschool bilinguals have increased thinking abilities compared to monolinguals.

How else can these tasks be described? Complex tasks, like the Theory of Mind tasks, require certain specific higher level thinking abilities that have been termed "executive functions" or "frontal lobe" functions.

Executive Function and Frontal Lobe Development

What are "executive functions?" According to the theory of cognitive development described by Baddeley (1996), executive functions are a type of higher-level cognitive function that requires careful control of attention. More specifically, in Baddeley's theory there is a part of human thinking called the "central executive." Its job is like that of an executive in a company: not to *do* the actual work, but to *direct* the cognitive work that is done. The central executive controls which cognitive functions receive attention in a given circumstance, and which cognitive functions are inhibited. A task that requires a great deal of attentional control or inhibition is referred to as "tapping into an executive function" (Baddeley, 1996).

Another term frequently used in conjunction with the ability to focus and control our attention is "frontal lobe" development. What are frontal lobe functions? Why is this term used somewhat interchangeably with executive functions? The ability to focus and control our attention is neurologically seated in the frontal and prefrontal cortex, the front most

part of the human brain behind the forehead. Development of this area is late to develop in children, as anyone who has been around a young child can attest when they admonish the child to "pay attention" and "stop doing that." One reason children are late to develop attentional control and inhibitory ability is because this frontal area is the final portion of the brain to develop through the increasing myelination of the neurons in this area. Myelination is a process by which the neurons are wrapped with non-neuronal brain cells called glial cells. These glial cells allow the neuron responses in synchrony. They appear white, and therefore these myelinated areas are referred to as white matter, in contrast to the grey matter of non-myelinated areas (Fuster, 2002a-d, 2008).

Behavioral Tests of Executive/Frontal Lobe Functioning in Children

Evidence from a number of non-language tasks suggests that preschool age bilingual children have better control over their attention and their inhibition, or executive or frontal lobe functions, than do their monolingual peers. One test used to assess executive function is the *Dimensional Change Card Sort* or DCCS (Frye, Zelazo, & Palfai, 1995); (Zelazo, Frye, & Rapus, 1996). This task, in its most basic form, contains cards that differ in two dimensions, such as color and shape. For example, some cards are red and some blue. The same cards also come in two other denominations, such as boat cards and car cards. The children are asked to sort the cards based on color. Then the game is switched and the children are asked to sort on the basis of the other category, shape. Young monolingual preschoolers, approximately 3 years of age, committed the error of continuing to sort the cards based on the first category (color), while older monolingual preschoolers, approximately 5 years of age, successfully sorted based on the new category (Zelazo, 2006). The bilingual subjects outperformed the monolingual subjects at a younger age when asked to inhibit paying attention to the perceptual differences in the cards that continue to distract the monolingual children, in this case colors.

What if a twist is put on the game? A twist was designed by Bialystok and Martin (2004) further to determine which type(s) of cognitive development are stronger in bilingual preschool subjects when compared to their monolingual peers. The first category involves some surface/perceptual attribute like color (red vs. blue). The second category involves something deeper in meaning, something more semantic/representational, such as function (toys vs. something to wear). In this case the children were asked to sort based on the surface/perceptual

category first, then they were switched to sorting along representational/semantic dimensions (toys vs. something to wear). When this twist had been added, the bilingual benefit disappeared. Bilingual and monolingual subjects alike committed the error of continuing to sort based on the first category instead of attending to the second category. This result suggests that the perceptual-to-perceptual shift is easier for bilinguals, but the perceptual-to-representational/semantic shift proved just as challenging to bilingual and monolingual preschoolers alike. Therefore, there are limits on the benefits of attentional control of the central executive or frontal lobes in bilinguals. Bialystok and Martin's study showed that young bilingual preschoolers demonstrated benefits only when there is selective inhibition of attention related to surface rather than deep meaning.

A study by Carlson and Meltzoff (2008) expanded research by Bialystok and others in multiple studies, producing a 9-test battery of executive function tasks, in which the performance of native bilingual children, those who are taught English through an "immersion program", was compared to their monolingual peers. Six subtests were categorized as those involving "conflicting information" regarding their cues for action. For example, the subjects were asked to sort on the basis of color, but if the card also had a gold star, the subjects were expected to sort on the basis of shape. Another subtest involved having the subjects play "Simon says." The other three subtests focused on the kindergarteners delaying their response according to the examiner's instructions. When independent tests were statistically grouped, the benefits of bilingualism were seen only on the tests where the children were presented conflicting information in their cues for action. In contrast, those subtests that assessed delaying responses did not show group differences (Carlson & Meltzoff, 2008). These findings can be seen as more evidence toward the hypothesis that bilinguals deal better with surface conflicting information tasks than monolinguals do.

The results of the study revealed that, even though the native bilingual children as a group had a lower socioeconomic status, the native bilingual speakers outperformed their monolingual peers, a finding consistent with the studies by Bialystok and Martin (2004). Carlson and Meltzoff's study also revealed that students who have been enrolled in an English immersion program did not perform differently than the monolingual subjects. These findings suggest that the bilingual advantage must be developed over an extended period of time, beginning at a very early age.

Bilingual Differences Beyond Early Childhood

Do the more advanced executive functions found in native bilingual preschoolers and kindergarteners persist throughout life? Bilingual differences have been found in young children in executive functions, specifically those that require attentional control and inhibition based on conflicting information (Bialystok & Craik, 2010). These bilingual benefits are seen in young children, but interestingly, the benefits become more muted in adulthood, present only when the task is at its most challenging (Costa, Hernández, & Sebastián-Gallés, 2008). Bilingual differences then re-emerge in late adulthood. It is possible that these periods of development where there are changing amounts of myelination and individual differences in neural development may be periods where the bilingual effect is most evident (Bialystok, Craik, & Luk, 2012).

Research has shown that frontal lobe functions are also among the earliest to decline, with the amount of white matter declining over later adult years, even as part of healthy aging (Bartzokis, Sultzer, Lu, Nuechterlein, Mintz, & Cummings, 2004). It is for this reason that these pivotal times of transition in development and change in childhood and later adulthood are of such great interest in the research of higher level cognitive functions such as attentional control. It is also why – if researchers suspect that higher level thinking, executive functions, or frontal lobe functions differ between bilinguals and monolinguals – they focus on these times of transition, childhood and old age, when attentional control and amounts of frontal white matter exhibit the greatest changes.

Bilingual Benefits in Old Age

Research of cognitive benefits in older bilingual individuals has been performed through both behavioral and neuroscientific studies. As was found in the previously cited studies with young bilingual children, there is a bilingual benefit in the executive functions of older adults. When Bialystok, Craik, and Luk (2008) administered a battery of tests to older bilingual and monolingual adults, the results were mixed. Language tasks were performed less well by the bilinguals, the working memory tasks were performed equally well by monolinguals and bilinguals, and the executive function tasks were performed better by the bilinguals (Bialystok, Craik, & Luk, 2008).

Results of a study by Bialystok, Craik, Klein, and Viswanathan (2004) revealed a bilingual advantage in older adults in a specific non-language executive function task, the Simon task. In this task, subjects

were presented a color block appearing in one of two colors, in this case red and blue. Both younger and older adult participants were asked to press the left key when presented a red block, but push the right key if presented a blue block. On some trials the color block was presented on the <u>same</u> side as the key. On other trials the color block was presented on the <u>opposite</u> side of the screen; for example on the left side of screen a blue block appears, cueing pressing of the far right key. On the second type of trials, each participant tries to inhibit the conflicting cue to press the button on the same side, resulting in slower reaction times and more mistakes for all subgroups of subjects. This task requires inhibition of response based on perceptual conflict. As expected, younger participants performed better than older adult participants. This result reflects the deterioration of white matter in the frontal lobes, causing executive functions to decline in old age. However, the older bilingual adults were found to perform better and faster on this task than the older monolingual adults, with a greater bilingual benefit for older compared to younger adults.

So there is additional evidence, this time on the other end of the life span, that there is an advantage in higher level cognitive processing in bilingual adults. With the increased percentage of the population reaching later age, and with overall life expectancy expanding, understanding healthy aging has become a focus of research. What is it about being bilingual that results in this advantage of appearing to slow cognitive decline in older adults? Neuroscience has been able to provide insight, particularly research focusing on the frontal regions of the brain.

More specifically, recent neuroscientific advances have allowed for direct exploration of differences in white matter myelination in the brains of bilinguals compared to monolinguals. It is known that neurons with a greater amount of white matter have water running <u>through</u> them (as compared to diffusing out), as occurs to a greater extent in unmyelinated gray matter. Diffusion tensor imaging (DTI) is structural magnetic resonance imaging that can detect these patterns of directional water paths in neurons and thus detect the amount of white matter in the brain. There is a decrease in white matter in old age seen throughout the brain, including the frontal areas of the brain. The important connections between this executive part of the brain and the more anterior portions of the brain are thought to be how this frontal executive area supplies attention and inhibition to other working areas of the brain. A recent study using DTI compared the brains of older bilingual and monolingual adults. More myelinated white matter was observed in the brains of the bilingual

participants, connecting both the hemispheres together as well as connecting frontal parts of the brain to more anterior parts (Luk, Bialystok, Craik, & Grady, 2011). This study of older adults and the bilingual brain stands out as measuring a population where the white matter of the frontal lobes is in flux, and where the bilingualism benefits appear very marked.

What Is The Benefit? Conclusions and Future Studies

What is it that bilinguals can do better than monolinguals? The research presented in this paper suggests that being bilingual has an effect if both languages are presented from an early age. In childhood, being bilingual seems to accelerate complex cognitive processing. While this advantage appears less marked during the peak of cognitive ability (young adulthood), underlying changes in cognitive abilities and neurological structure carry forward into older adulthood, slowing the cognitive decline.

There are still many questions to ask about the nature of the bilingualism and how it plays a role in generating the bilingual benefit. How early must an individual become bilingual in order to gain the "bilingual advantage"? Also, what are the multiple ways to be bilingual and the degrees of bilingualism? For example, there is the passive bilingual, completely proficient in a first language, who may be able to understand what is spoken in the second language but unable to produce speech in the second language. Will these individuals still show the bilingual benefit? There is also the question of the environment in which the two languages are spoken. If an individual speaks only his first language at home, but uses a second language exclusively at school or work, is that the same as someone who is code switching all day (switching back and forth between languages, sometimes within the same sentence)? What happens to the individual who learned his native language as a young child, then immigrated to a country using an entirely different language? Will the suppression of the first language affect the neurological bilingual advantage in later years? With so many questions still unanswered and new techniques of neuroscience and assessment to help answer them, much will be learned about the fascinating phenomenon of the bilingual benefit.

References

Baddeley, A. D. (1996). Exploring the central executive. *Quarterly Journal of Experimental Psychology. 49A*, 5-28.

Bartzokis, G., Sultzer, D., Lu, Po H., Nuechterlein, K. H., Mintz, J., & Cummings, J. L. (2004). Heterogeneous age-related breakdown of white matter structural integrity: Implications for cortical "disconnection" in aging and Alzheimer's disease. *Neurobiology of Aging, 25*, 843-51.

Bialystok, E., & Craik, F. I. M. (2010). Structure and process in lifespan cognitive development. In: *The Handbook of Life-Span Development: Biology, Cognition and Methods Across the Life-Span.* R. M. Lerner & W. F. Overton (Eds), Hoboken, NJ: Wiley, pp. 195-225.

Bialystok, E., Craik, F. I. M., Green, D. W., & Gollan, T. H. (2009). Bilingual minds. *Psychological Science in the Public Interest. 10*, 89-129.

Bialystok, E., Craik, F. I. M., Klein, R., & Viswanathan, M. (2004). Bilingualism, aging, and cognitive control: Evidence from the Simon Task. *Psychology and Aging. 19*, 290–303.

Bialystok, E., Craik, F. I. M., & Luk, G. (2008). Lexical access in bilinguals: Effects of vocabulary size and executive control. *Journal of Neurolinguistics*, *21*, 522-538.

Bialystok, E., Craik, F. I. M., & Luk, G. (2012). Bilingualism: Consequences for mind and brain. *Trends in Cognitive Sciences*, *16*, 240-250.

Bialystok, E., & Luk, G. (2011). Receptive vocabulary differences in monolingual and bilingual adults. *Bilingualism: Language and Cognition*, *15*, 397-401.

Bialystok, E., Luk, G., Peets, K. F., & Yang, S. (2010). Receptive vocabulary differences in monolingual and bilingual children. *Bilingualism: Language and Cognition*, *13*, 525-531.

Bialystok, E., & Martin, M. M. (2004). Attention and inhibition in bilingual children: Evidence from the dimensional change card sort task. *Developmental Science*, *7*, 325-339.

Carlson, S. M., & Meltzoff, A. N. (2008). Bilingual experience and executive functioning in young children. *Developmental Science*. *11*, 282–298.

Costa, A., Hernández, M., & Sebastián-Gallés, N. (2008). Bilingualism aids conflict resolution: Evidence from the ANT task. *Cognition*. *106*, 59–86.

Farhadian, M., Abdullah, R., Mansor, M., Redzuan, M., Gazanizadand, N., & Kumar, V. (2010). Theory of mind in bilingual and monolingual preschool children. *Journal of Psychology. 1*, 39-46.

Frye, D., Zelazo, P. D., & Palfai, T. (1995). Theory of mind and rule-based reasoning. *Cognitive Development. 10*, 483-527.

Fuster, J. M. (2002a). Prefrontal cortex in temporal organization of action. In: *The Handbook of Brain Theory and Neural Networks*. Second Edition. M.A. Arbib (Ed.), Boston, Mass: The MIT Press, pp. 905-910.

Fuster, J. M. (2002b). Cortical memory. In: *The Handbook of Brain Theory and Neural Networks.* Second Edition. M.A. Arbib (Ed.), Boston, Mass: The MIT Press, pp. 290-294.

Fuster, J. M.(2002c). Frontal lobe and cognitive development. *Journal of Neurocytology. 31*, 373-385.

Fuster, J. M. (2002d). Physiology of the executive functions: The perception-action cycle. In: *Principles of Frontal Lobe Function.* D.T. Stuss & R.T. Knight

(Eds.), Oxford, UK: Oxford University Press, pp. 96-108.

Fuster, J. M. (2008). *The Prefrontal Cortex* (Fourth Edition) London, UK: Academic Press. Gollan, T. H., & Ferreira, V.S. (2009). Should I stay or should I switch? A cost-benefit analysis of voluntary language switching in young and aging bilinguals. *Journal of Experimental Psychology: Learning, Memory, & Cognition. 35*, 640-665.

Grosjean, F. (2010). *Bilingual: Life and Reality*. Cambridge, Mass: Harvard University Press.

Hatzidaki, A., Branigan, H. P., & Pickering, M. J. (2011). Co-activation of syntax in bilingual language production. *Cognitive Psychology. 62*, 123–150.

Kovács, A. M. (2009). Early bilingualism enhances mechanisms of false-belief reasoning. *Developmental Science*, *12*, 48–54.

Kroll, J. F., Bobb, S. C., Misra, M., & Guo, T. (2008). Language selection in bilingual speech: Evidence for inhibitory processes. *Acta Psychologica. 128*, 416-430.

Luk, G., Bialystok, E., Craik,F. I., & Grady, C. L. (2011). Lifelong bilingualism maintains white matter integrity in older adults. *Journal of Neuroscience. 31*, 16808-16813.

Martin, C. D., Dering, B., Thomas, E. M., & Thierry, G. (2009). Brain potentials reveal semantic priming in both the 'active' and the 'non-attended' language of early bilinguals. *Neuroimage, 47*, 326-333.

Shin, H. B., & Kominski, R. A. (2010). *Language Use in the United States:* American Community Survey Reports, ACS-12. Washington, DC: U.S. Bureau of the Census; 2010.

Wang ,Y, Xue, G., Chen C., Xue, F., & Dong Q. (2007). Neural bases of asymmetric language switching in second-language learners: An ER-fMRI study. *Neuroimage*, *35*, 822-870.

Werker, J. F., & Byers-Heinlein, K. (2008). Bilingualism in infancy: First steps in perception and comprehension, *Trends in Cognitive Sciences*, *12*, 144-151.

Zelazo, P. D. (2006). The dimensional change card sort (DCCS): A method of assessing executive function in children. *Nature Protocols, 1*, 297-301.

Zelazo, P. D., Frye, D., & Rapus, T. (1996). An age-related dissociation between knowing rules and using them. *Cognitive Development, 11*, 37-63.

Bio

Dana Byrd's general interest is understanding cognition through the life span and neurological changes that underlie both age and special population differences in cognition. She has explored life-span development of higher level cognition utilizing behavior, electroencephalogram, and other psychophysiological measures. She holds bachelors (New College), masters, and PhD degrees (both at the University of Florida) in Psychology. She did Postdoc work at Columbia Medical University, and has been on the faculty at Texas A&M University-Kingsville since 2011.

Strategic Management of Scientific Research Organizations

Paul Arveson

Balanced Scorecard Institute, Washington, DC

Abstract

Scientific research organizations and laboratories are increasingly facing strategic challenges, such as climate change and health care, and solutions require enhanced strategic thinking. Learning, through double-loop feedback systems, takes place in scientific research disciplines and engineering fields. Similarly, research organizations can implement strategies within the framework of a double-loop learning system as found in fields of research. Strategic thinking about the performance of research organizations can be enhanced through the use of an innovative conceptual tool called a strategy map. Strategy maps help to make organizational strategies more visible and measurable. This article shows how strategy mapping fits within the larger "double loop" context of a scientific research organization's strategic performance management system and its inherent feedback loops. The article also describes the features of strategy maps and how they can help the leaders of scientific research organizations make strategic decisions and manage more effectively.

Introduction

In the management of scientific research organizations, a nagging question arises: Since the nature of basic research is exploratory, scientists do not know in advance the best way to proceed. If they did, they would pursue that direction and reject the alternatives. Since they do not, research is inherently wasteful of time and resources. This dilemma has been described as one of the "grand challenges" of basic research (Valdez 2001).

Commercial organizations that have a research or innovation department need to justify research budgets by demonstrating fruitful results to their stakeholders. A similar challenge is faced by mission-oriented governmental organizations. The Government Performance and Results Act (GPRA) of 1993 (and its revisions) require all Federal agencies to develop strategic plans and performance measurement plans, in order to justify their funding. Although nonprofit and governmental organizations do not have profit as their mission, they do cost money and

are expected to be good stewards of it. Hence it is imperative for all research organizations to learn how to "do more with less."

Dr. Ron Kostoff has studied the management of government research and the process of evaluating that research for several decades. He recommended that "program peer review should be integrated seamlessly into the organization's business operations ... It should not be incorporated in the management tools as an afterthought, as is the case in practice today, but rather should be part of the organization's front-end design" (Kostoff 2003).

As a step in this direction, this article offers an approach for integrating strategy and performance evaluation into a system analogous to that of the scientific research process itself. The article describes a simplified model of the scientific research process in terms of hypothesis testing. Next this model will be applied to an organization's strategic management process, which aims to improve the productivity of research. A "strategy map" is introduced as a tool for the formulation of the organization's strategic hypothesis. This extends what will be described as a "double-loop learning process" to the organization itself, so that its research performance can be evaluated and improved over time.

Scientific Hypothesis Testing as Double-Loop Learning

Science is a learning process which is continuous, unending, and always subject to future revision. Science takes practical steps – sometimes revolutionary, but often incremental – toward more well-tested models. In practice, research does not proceed in a step-by-step fashion; there are many twists and turns, and the activities may occur in a different order or even be separated by many years. Real scientific work involves the "tacit dimension" of research described by Polanyi: "Because it is tacit and not explicit, it is not fully replicable and the establishment of a theory depends on personal insight and peer review within the scientific community" (Polanyi 1967).

Despite the risks of oversimplification, it is evident to the author that scientific hypothesis testing often proceeds via two feedback loops:

a) a loop involving the formulation and revision of hypotheses (with the sequence, hypothesis-prediction-evaluation-revision); and

b) a second loop involving the testing and revision of experiments (with the sequence, experiment-data-evaluation-revision).

Such a "double-loop learning" system involves two interconnected feedback loops (Argyris and Schön 1974). Figure 1 illustrates the double-loop learning process applied to scientific hypothesis testing.

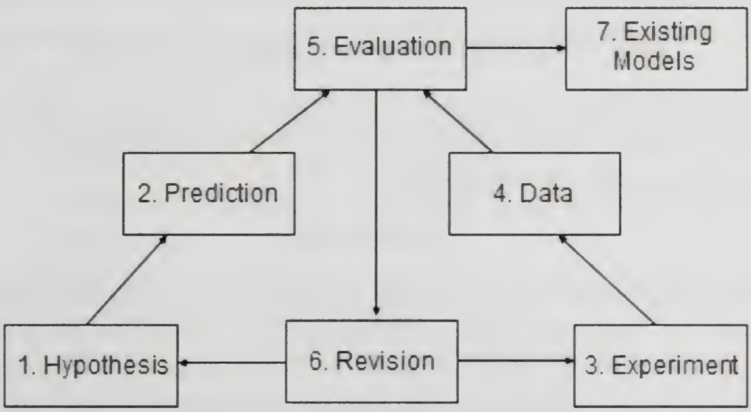

Figure 1. Double-Loop Learning in Scientific Hypothesis Testing

In general, the process includes these types of activities (not steps):

1. **Hypothesis:** A plausible explanation of some natural phenomenon is proposed.
2. **Prediction:** Based on the hypothesis, observable and measurable consequences are deduced.
3. **Experiment:** Activities pertinent to the hypothesis are conducted to test its predictions (e.g., apparatus construction, observations, simulations, documentation).
4. **Data:** Quantitative measurements commensurate with predictions are recorded and processed to reduce uncertainties due to bias, errors and randomness.
5. **Evaluation:** Predictions and data are compared, with due consideration of statistical uncertainties. A successful evaluation requires not only agreement between the data and predictions, but also a determination that excludes other alternative models (Giere *et al.* 1998).
6. **Revision:** An evaluation that fails to show agreement may lead researchers to make revisions in either the hypothesis or

the experiment (*e.g.*, the earlier experiment may not have been sensitive enough, or may not have yielded data commensurate with the predictions).

7. **Existing models:** This activity involves the collection of tested hypotheses and their predictions that have not been falsified so far (Popper 1968).

In Figure 1, the left-hand loop is represented by activities 1, 2, 5, and 6. The right-hand loop is represented by activities 3, 4, 5, and 6.

More "Double-Loop Learning" Examples

There are many examples of systems containing double feedback loops that converge and eventually result in an accumulation of learning. This section provides two examples.

Engineering

The first example is provided by applying the double loop concept to the field of engineering. In engineering, a goal is to arrive at an optimum design for a product or process. The activities involve two loops or groups of actions. The sequence below describes the activities that are repeated using the same pattern of loops and numbered boxes until a prototype is developed that meets specifications, where possible:

1. A prototype design is created based on existing knowledge.
2. It is desired that the prototype will meet certain quantitative design specifications (along with generally desired requirements such as low cost, limits on time to build and maintain, etc.).
3. The prototype is tested under real-world or simulated real-world conditions.
4. Data from the tests are collected and documented.
5. The data are compared with the specifications. If all the specifications are met, the prototype design may move to production.
6. If there is lack of compliance with the specifications, or if the evaluation is inconclusive, revisions are necessary. Either the design must be revised, or additional testing must be done, or both.
7. When all specifications have been met, the process results in an "optimized design" ready for production.

Similar to above, the loops involve these two groups of activities: The first loop involves activities 1, 2, 5, and 6. The second loop involves activities 3, 4, 5, and 6.

Evolution

The field of evolution provides a second example. Existing species of life on earth represent millions of years of continuous confrontation between expressed genes and their environment. In a broad-brush description, the following activities have operated over time (the numbers below correspond to the numbers in the boxes of the double-loop learning process illustrated in Figure 1):

1. A genome, including its mutations and recombinations, is expressed in cells by reproduction.
2. Numerous individual organisms with various phenotypes are produced.
3. Life exists in an environment which contains a variety of changing threats and opportunities.
4. Individuals are exposed to the environment.
5. Depending on their response to features of the environment, individuals are selected for increased or decreased reproduction (natural selection).
6. Mutations continue to occur, and the environment continues to change.
7. At any point in time, the existing life forms are those that have been most successful in reproducing throughout their cumulative exposures to changing environments.

Again, the loops are represented by activities 1, 2, 5, and 6 and activities 3, 4, 5, and 6.

Both of these examples show the same general pattern, as noted: a system of two feedback loops that converge and eventually result in an accumulation of learning.

Double-Loop Learning in Scientific Research Organizations

The above examples serve to suggest the wide range of applications of the double-loop learning system. How can a double-loop system be implemented to manage and evaluate the performance of a scientific research organization?

An organization is a dynamic system: “a set of things … interconnected in such a way that they produce their own pattern of

behavior over time" (Meadows 2008). A key feature of dynamic systems is that they contain feedback loops (Nay and Kay 1982, Haines 2000).

Scientific research organizations and their activities can be thought of as having two feedback systems in operation which are analogous to the learning loops described earlier:

a) The inner system is the conduct of scientific research proper, in which success depends on posing insightful hypotheses and focusing on the most promising observations and experiments.

b) The outer system has management challenges similar to those in any other organization. Management in the outer system does not encounter "grand challenges." Here, the organization is trying to enable scientists to conduct research activities more efficiently. Its managers seek strategies for finding the right skills and technology, better ways to organize, better procedures to follow and better ways to evaluate performance. Such improvements help to drive down cost, duplication, and time delays in research.

In most scientific research organizations, more can be done to improve the efficiency of the outer system of management, thereby enabling the inner system of research proper to become more effective, operating with fewer delays and resource shortages. The intent is not to presume to improve scientific research *per se* (which would require specialized expertise in narrow fields of research), but rather to improve the management system supporting that research.

Figure 2 shows a double-loop system with the labels changed so that the context is that of a scientific research organization, as follows:

1. **Strategy:** The scientific research organization's planners formulate a strategic hypothesis: a specific vision and "road map" for achieving it.
2. **Desired results:** Activity 2, desired results, represents the intended long-term improvements in the organization's accomplishments expected from the strategy.
3. **Strategic initiatives:** Activity 3, strategic initiatives, includes new projects and changes in operations and budget allocations that are aimed at improving performance to reach the desired results.
4. **Actual results:** Activity 4, measuring performance or actual results, relates to quantitative and qualitative measurements

of end results but also intermediate results or "leading indicators" that managers can use to forecast longer-term outcomes. An approach for developing these intermediate measures of performance will be presented in the next section.

5. **Evaluation:** Typically, senior leaders in an organization will periodically convene high-level strategy reviews, in which everything is questioned. One of the main questions addressed is the comparison question: Do the data show that desired results were met? Of course it could be that circumstances beyond the organization's control caused the results, or variations in data may make comparisons inconclusive.
6. **Revision:** If the desired results were not achieved, there may be a need to revise the strategic initiatives, how they are measured, allocation of resources, or other activities. Or, the data may indicate a need to revise the strategic hypothesis itself.
7. **Successful strategies:** Over time, the organization learns what strategies are more or less successful, based on measures of strategic performance. Successful strategies embody the knowledge and experience of the organization's leaders.

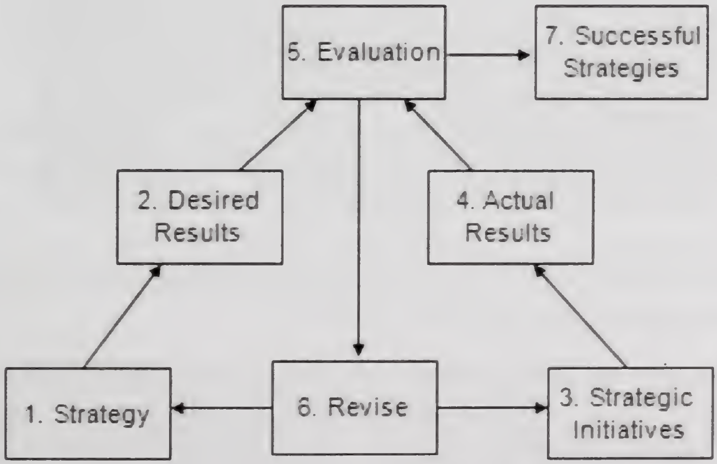

Figure 2. Strategic Management Model for a Scientific Research Organization

The Left-Hand Feedback Loop: Organizational Strategy

The first feedback loop is all about strategy. Scientific research organizations are increasingly facing strategic challenges, such as climate change and health care. Solutions require enhanced strategic thinking.

A scientific research organization must define its strategy (box 1) before it prescribes new strategic initiatives (box 3) or measures performance (box 4). The organization must first establish agreement on the destination, and then propose how to get there. Strategy should come before organization design, budgeting, operational plans, or process improvements – and before establishing key performance indicators or collecting performance measures (Rohm 2002). Performance measurement and evaluation then supports strategic management, not merely operations or compliance (Apple, Inc. 2011). Strategy should set the context for what is considered high or low performance.

A strategy map is a relatively new kind of visual tool that describes an organization's strategic hypothesis (box 1 in Figure 2). A strategy map illustrates a chain of *strategic objectives* drawn as ovals and linked together with arrows that lead to a long-term and strategic desired result for the organization (box 2, desired results, in Figure 2).

The strategy map is becoming a popular management tool because it makes strategic planning more practical and visual. For example, the book *Strategy Maps* (Kaplan and Norton 2004) is devoted entirely to the concept of strategy mapping, and contains examples from a variety of organizations. A strategy map is <u>not</u> an organization chart, flowchart, logic model, work breakdown structure, technology roadmap, system diagram, or program plan.

Figure 3 is a hypothetical strategy map for a scientific research organization. (In practice, no two organizations' strategy maps are alike, but this hypothetical figure illustrates some key features and best practices in strategy mapping). It is recommended that a strategy map be created in facilitated workshops by a diverse, cross-functional planning team within the organization (Rohm 2002).

The four rectangular areas of the strategy map in Figure 3 present four "perspectives" of organizational performance: organizational capacity, internal process, finance, and stakeholder perspectives. These indicators offer a "balanced scorecard" of mostly leading indicators of future organizational performance. The order of the four perspectives of organizational performance is important. Figure 3 shows the proper

arrangement of the perspectives for a public sector or non-profit organization. For a private sector organization, the financial perspective would be on top.

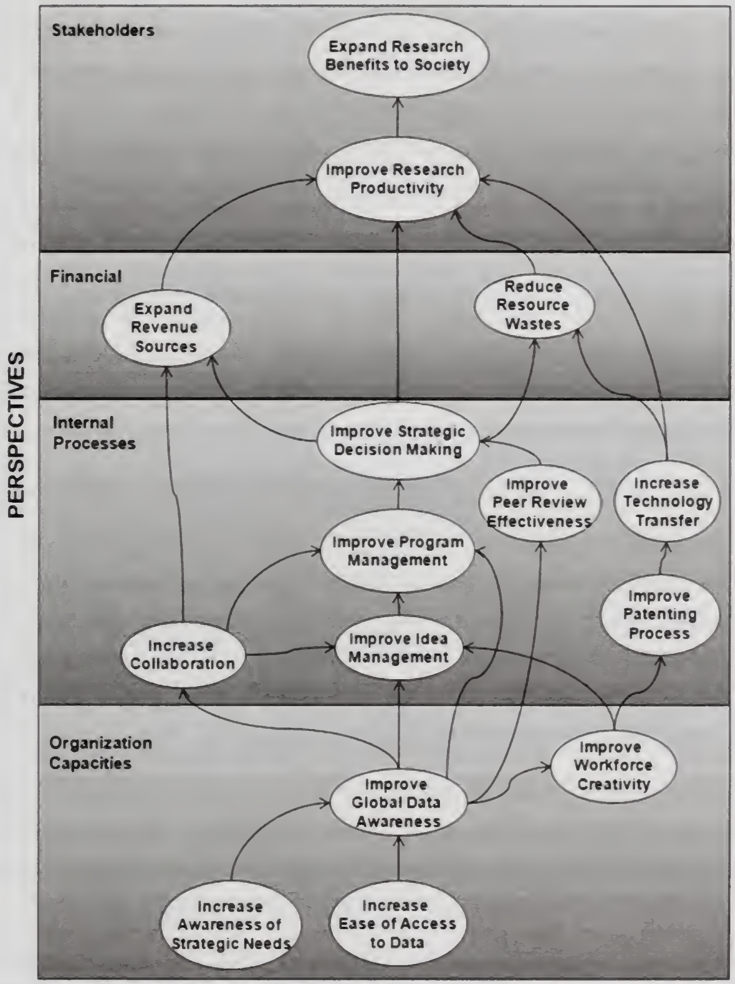

Figure 3. Hypothetical Strategy Map for a Non-profit Research Organization

A strategic objective (each oval on Figure 3) specifies – in a few words – *what* needs to be improved. Each strategic objective begins with an imperative verb that suggests continuous improvement, such as *improve, increase* or *reduce*. Strategic objectives are written in "high-altitude" language. They are not projects; many projects may support improvement of one objective. Further development of the strategic plan is

necessary to identify strategic projects that align with the strategic objectives.

The linked strategic objectives form a chain of cause and effect. Following the arrows, the strategy map can be read from the bottom up. The strategy map as a whole prescribes how the intermediate results lead to the final strategic result at the top of the map – which equates to desired results in Figure 2. In this non-profit example, one of the cause-effect chains would read as follows, starting at the bottom:

> *"If we increase ease of access to data, then we will be able to improve global data awareness. This will lead to increased collaboration, internally and externally, and possibly expand revenue sources. It will also allow managers to conduct more effective peer reviews, which will help to improve strategic decision making [e.g., budgeting], which will reduce resource waste and improve research productivity, ultimately expanding research benefits to society.*

Another cause-effect chain from the same strategy map would read as follows, starting at a different place in the bottom quadrant:

> *If we improve workforce creativity [e.g. by hiring smart people and placing them in teams], this will improve idea management and/or patenting processes, which will lead to increased technology transfer and improved research productivity. The end result will be to expand research benefits to society."*

Notice that all the "roads" on the strategy map go in one direction only. Strategy maps provide a one-way road map. *There are no backward paths or feedback loops on a strategy map*, for why would anyone want to propose efforts that go against achieving the strategic results?

Within the context of strategic planning, the strategy map addresses the question, "Are we doing the right things?" in contrast to the operational question, "Are we doing things right?"

People who study system dynamics tend to see strategy maps as incomplete because they are missing feedback loops (Akkermans and van Oorschot 2002; Bianchi and Montemaggiore 2008; Kim *et al.* 2006; Linard and Dvorsky 2001). However, a strategy map is not intended to be a description of an organization's systems or processes or dynamics or external environment. Instead, a strategy map is a *piece* of the system (the "hypothesis" box and desired results box), not the whole system. There is

a proper place for feedback, but it is not on the strategy map; rather, it is within the double-loop strategic management system illustrated in Figure 2.

The basic framework of the four "perspectives" introduced by Kaplan and Norton (1993) is a robust, generally-applicable framework for strategy mapping. It is also scalable – it can serve the planning needs of small non-profits, huge multinational corporations, or large government agencies. The U.S. Army and other military branches are increasingly adopting strategy mapping. Most importantly, in terms of the subject of this article, strategy maps are also applicable to scientific research organizations.

The Right-Hand Feedback Loop: Measuring the Strategy

Earlier approaches to organization improvement and performance measurement, such as Total Quality Management (TQM) and Six Sigma methods, do not fit well within a scientific research organization which does not have repetitive manufacturing processes or tangible products. Application of such methods in research organizations often results in measuring the wrong things and "measurement fatigue" because the focus tends to be on operational rather than *strategic* performance measures.

How can managers of scientific research organizations identify strategic performance indicators? *They are simply the strategic objectives on the strategy map that are being "improved," "increased," "reduced," etc.* These are the intermediate results (according to the planning team) most likely to lead to the "desired results" (box 2 on Figure 2). Once strategic objectives are defined in the ovals on the strategy map, strategic performance indicators to measure these objectives follow directly.

So-called "intangible" or qualitative metrics are often needed. For example, to measure the strategic objective, "Increase ease of access to data," the measurement may involve a survey to determine the level of complaints or delays in data access. To measure the strategic objective "Increase strategic decision making," it may be necessary to conduct structured interviews of managers to assess their awareness of the strategic plan and how they are using it to make decisions.

If measurement is defined as "observations that reduce our uncertainty in the value of a quantity," then anything real can be measured (Hubbard 2010). Kostoff (2005) recognized that gathering useful research metrics may require technical tools such as large databases, automated text

data mining, bibliometrics, *etc.* – the "information infrastructure" that managers can put in place to enable scientists to compile information efficiently. But in the case of scientific research programs, qualitative measures, including peer review, are often more meaningful than quantitative measures. Kostoff (1997) argued that peer review is a necessary, if not sufficient procedure for the evaluation of scientific research programs. Hence some federal research agencies have been permitted to provide qualitative program assessments to the Office of Management and Budget, not merely numerical data.

Peer review serves to maintain the focus of a project or program, build credibility and share lessons learned, according to Dr. Daniel Lehman, Director of the Office of Project Assessment in the Office of Science at the U.S. Department of Energy (Lehman 2011). However, peer review can be costly and time-constrained because there are often few qualified peers. Therefore, certain considerations must go into the design of an effective program peer review (Kostoff 2003). Nay and Kay (1982) offer an important preliminary consideration: Has the program been implemented to the extent that it can be evaluated?

As strategies are evaluated (box 5 on Figure 2), feedback comes through the double-loop learning system. Through regular, periodic evaluations of strategic performance, the strategy – including strategic objectives, performance measures derived from the strategic objectives, strategic initiatives, and even budgets – can be revised. This management system establishes a balance between consistency of the desired strategic result(s) and flexibility of management decision-making based on the feedback loops.

Conclusion

Physicists have a saying, "Many a beautiful theory has been destroyed by one ugly fact." In an organization, "ugly facts" represent unequivocal performance data confronting executives and board members.

The leaders of strategy-focused organizations, however, will have a head start on dealing with performance data through: (1) a double feedback loop approach to strategic performance management; and (2) a strategy map with performance measures for each of the strategic objectives. The strategy map will include customer (or stakeholder) feedback data, as well as measures of financial costs, internal process efficiencies and organization capacities – all leading indicators of future results. Weaknesses in these strategic performance measures can guide the

leaders of research organizations to make informed decisions about what specifically needs to be revised to improve strategic performance. Over time, such a management system is designed to encourage innovative strategies and initiatives to improve research effectiveness and productivity (box 7, successful strategies).

. References

Akkermans, H. and van Oorschot, K. (2002). "Developing a Balanced Scorecard with System Dynamics." *Proceedings of the 20th International Conference of the System Dynamics Society,* May 2002. Palermo, Italy. http://www.systemdynamics.org/conferences/2002/proceed/papers/Akkerma1.pdf

Apple, Inc. (2011). *Beyond Compliance: Apple Supplier Responsibility, 2011 Progress Report.* http://www.apple.com/supplierresponsibility/beyond-compliance.html

Argyris, M. and Schön, D. (1974). *Theory in Practice. Increasing Professional Effectiveness*. San Francisco: Jossey-Bass.

Balanced Scorecard Institute (2010). *The Strategic Management Maturity Model.*

http://www.balancedscorecard.org/Portals/0/PDF/BSCIStrategicManagementMaturityModel.pdf

Bianchi, C. and Montemaggiore, G. B. (2008). "Enhancing strategy design and planning in public utilities through 'dynamic' balanced scorecards" (pp. 175-213). *System Dynamics Review 24*(2).

Giere, R., Bickle, J. and Mauldin, R. (2006). *Understanding Scientific Reasoning.* Belmont, CA: Thompson Wadsworth.

Haines, S. (2000). *Strategic and Systems Thinking.* San Diego: Systems Thinking Press.

Hubbard, D. (2010). *How to Measure Anything: Finding the Value of "Intangibles"* in *Business.* 2nd ed. New York, NY: Wiley.

Kaplan, R. and Norton, D. (1993). "Using the Balanced Scorecard as a Strategic Management System," *Harvard Business Review*. Jan.-Feb. 1996.

Kaplan, R. and Norton, D. (2004). *Strategy Maps – Converting Intangible Assets into Tangible Outcomes.* Boston, MA: Harvard Business School Press.

Kim, J., Park, S., & Kim, S. (2006). "On Building a Dynamic BSC Model for Strategic *Performance* Measurement in Public Sector." *Proceedings of the 24th International Conference of the System Dynamics Society.* , July 2006 Nijmegen, The Netherlands, http://www.systemdynamics.org/conferences/2006/proceed/papers/KIM124.pdf .

Kostoff, R. (1997). "Peer Review: The Appropriate GPRA Metric for Research" (p. 651). *Science* 277.

Kostoff, R. (2003). "Science and Technology Peer Review: GPRA", http://www.dtic.mil/dtic/tr/fulltext/u2/a418868.pdf

Kostoff, R. (2005). "Encouraging Discovery and Innovation" (p. 245). *Science* 309.

Kotter, J.P. (1996). *Leading Change*. Boston: Harvard University Press.

Kuhn, T. (1962). *The Structure of Scientific Revolutions.* Chicago: University of Chicago Press.

Lehman, D. (2011). "Office of Science Peer Reviews 101." PowerPoint presentation, Office of Project Assessment, Office of Science, U.S. Department of Energy. http://energy.gov/sites/prod/files/maprod/documents/16-1045_Lehman.pdf

Liker, J. (2004). *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer.* New York, NY: McGraw-Hill.

Linard, K. and Dvorsky, L. (2001). "A Dynamic Balanced Scorecard Template for Public Sector Agencies." *Proceedings of the Australasian Evaluation Society.* http://www.systemdynamics.org/conferences/2000/PDFs/linard34.pdf .

Mayer, M. (2006). "Ideas come from everywhere." Presentation from Stanford Business School. Online: http://www.udemy.com/ideas-come-from-everywhere/

Meadows, D. (2008). p. 2. *Thinking in Systems.* White River Junction, VT: Chelsea Green.

Nay, J. N. and Kay, P. (1982). *Government Oversight and Evaluability Assessment.* Lexington, MA: Lexington Books. Available online at: http://www.the-dilettante.org/Evaluability%20Assessment/Book.pdf

Polanyi, M. (1958). *Personal Knowledge: Towards a Post-Critical Philosophy* (pp. 142-145). London: Routledge and Kegan Paul.

Polanyi, M. (1967). *The Tacit Dimension* (pp. 24-25). New York, NY: Doubleday & Co.

Popper, K. (1968). *The Logic of Scientific Discovery* (p. 265). New York: Harper & Row.

Rohm, H. (2002). "A Balancing Act: Developing and Using Balanced Scorecard Systems," *PERFORM*, v. 2, no. 2.

US Department of Energy, Office of the Chief Financial Officer, DOE FY 2013 Budget Request, http://www.cfo.doe.gov/budget/13budget/content/volume4.pdf

Valdez, W., "Grand Challenges of Basic Research", presentation to DOE Office of Science employees (2001).

Bio

Paul Arveson's first career was as a physicist in the civilian Navy. He managed projects in acoustics, oceanography, signal processing and analysis, and published numerous technical papers in these fields. In the 1990s, he earned a Master's degree in Computer System Management and a CIO Certificate from the National Defense University. In 1998, he partnered with Howard Rohm to create the Balanced Scorecard Institute which provides strategic management training and consulting services to all kinds of organizations.

Addressing Eastern Shore and Chesapeake Bay Environmental Issues and Economic Development: University Research and Education

Sally A. Rood

Science Policy Works International, Clifton, Virginia

Abstract

The Chesapeake Bay/ Eastern Shore region has experienced dramatic changes and challenges environmentally. This has created rich research opportunities for the region's universities committed to improving environmental quality. Six university programs that focus on the environmental concerns of the region are described -- including their facilities and examples of their research contributions and STEM education and outreach. Also discussed are the recent history of the regional ecosystem and the socio-economics of the area's communities. In addition to contributing to environmental quality, the university programs can be leveraged toward science and technology-based economic development on a regional scale through a strategy for a regional innovation cluster. This would foster a knowledge-based workforce, university-industry collaborations, technology transfer, entrepreneurship, and business development.

Introduction: Critical Environmental Conditions

The Delmarva Peninsula's "Eastern Shore" region is bounded on the west by the Chesapeake Bay and on the southeast by the Atlantic Ocean. Both the bay and coastal ecosystem are national environmental treasures.

There are notable activities underway at each of six universities on the Eastern Shore. These research programs are contributing to the quality of the local environment on the shore. They are also contributing indirectly to the region's economic development. Their efforts can be better harnessed and targeted toward the common goal of creating a concerted strategy for an environmental science and technology-based regional innovation cluster.

The Dynamic Seaward Side

The Atlantic Ocean side of the Eastern shore offers one of the few remaining undeveloped areas along the Atlantic seaboard available for the

study of coastal barrier ecosystems. It has a long expanse of pristine beaches and large coastal wilderness areas. The Nature Conservancy created the Virginia Coast Reserve in the 1970s to protect a chain of 14 barrier islands. The preserve comprises some 40,000 acres and extends about 70 miles along the lower Atlantic shore of the Delmarva Peninsula. It has also been designated by the United Nations as an International Man and Biosphere Reserve. The northern end of the preserve features the Chincoteague National Wildlife Refuge and the southern end features the Eastern Shore National Wildlife Refuge.

Proceeding north to south, the larger of the barrier islands are: Chincoteague, Assateague, Wallops, Assawoman, Hog, Wreck, and Smith.[1] Assateague Island is actually a system of barrier islands about 27 miles long and averaging a half-mile wide. The islands are separated from one another by deep inlets. The islands are bounded on the east by the ocean and on the west by the coastal bays that separate them from land.

These barrier islands experience dramatic rates of shoreline change. As they migrate toward land in response to the rising sea level, the change can be as much as 40 feet in a single year. Wreck Island, for example, has lost 300 yards on its northern end in recent years. In addition to long-term climate change, critical natural events such as storms also cause change. Until a major hurricane in 1933, some of the barrier islands were populated with pine forests and small villages, and several islands had a few hundred inhabitants, structures, and Coast Guard stations. The hurricane eroded and submerged the woodland and dunes. Both the hurricane and disease wiped out the underwater seagrass decades ago. Because seagrass serves as a nursery for wildlife like shellfish, the shellfish subsequently disappeared as well.

The barrier islands are now largely sandy environments that help to buffer the Eastern Shore communities from storms. The island ecosystem also features lagoons, tidal marshes, and mainland watersheds. On the side of the islands facing land, there are broad shallow bays and extensive salt marshes adjacent to forested uplands. The seagrass in the lagoons acts as a seaside filter for pollutants and excess watershed nutrients.

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[1]Other islands are: Metompkin, Cedar, Paramore, Cobb, Ship Shoal, Myrtle, and Mockhorn. Many, but not all, of the islands that serve as environmental research sites are owned by The Nature Conservancy. Chincoteague and Wallops Islands, for example, are not part of the Reserve.

Research Opportunities

The barrier island ecosystem shelters more than 250 species of raptors, shorebirds, and songbirds and is one of the most important migratory bird stopover habitats on Earth.[2] Several of the islands feature complex and heterogeneous landscapes where walking just a few yards can introduce major differences in habitat. All of these factors make the ocean side an ideal place to study wildlife and the natural processes of landscape change. It has been called a "high-speed landscape" because changes that might take decades elsewhere can be observed in a few years. Short-term disturbances – such as storms and species invasions – interact with slower more progressive environmental changes to produce the region's geographic and biological dynamics.

The Delicate Chesapeake Bay

Directly surrounded by the states of Maryland and Virginia, the Chesapeake Bay is the largest estuary in the United States. It is approximately 200 miles long and 30 miles wide at its widest point, south of the mouth of the Potomac River. At its narrowest point, the bay is 2.8 miles wide. The shoreline extends more than 11,000 miles. The bay's watershed land-to-water ratio of 14:1 is the largest ratio of any coastal water body in the world. The bay is a drainage basin for the District of Columbia and parts of six states. The watershed states are: New York, Pennsylvania, Delaware, Maryland, Virginia, and West Virginia. More than 150 rivers and streams drain into the bay from these states. Figure 1 shows a map of the bay and its watershed states.

The bay ecosystem consists of the bay itself, its tidal rivers and streams, and all the plant and animal life it supports. The bay is mostly known for its seafood production, especially crabs, clams, and oysters. The bay's salinity is ideal for oysters, so the bay has long been considered one of the world's most productive oyster growing areas.

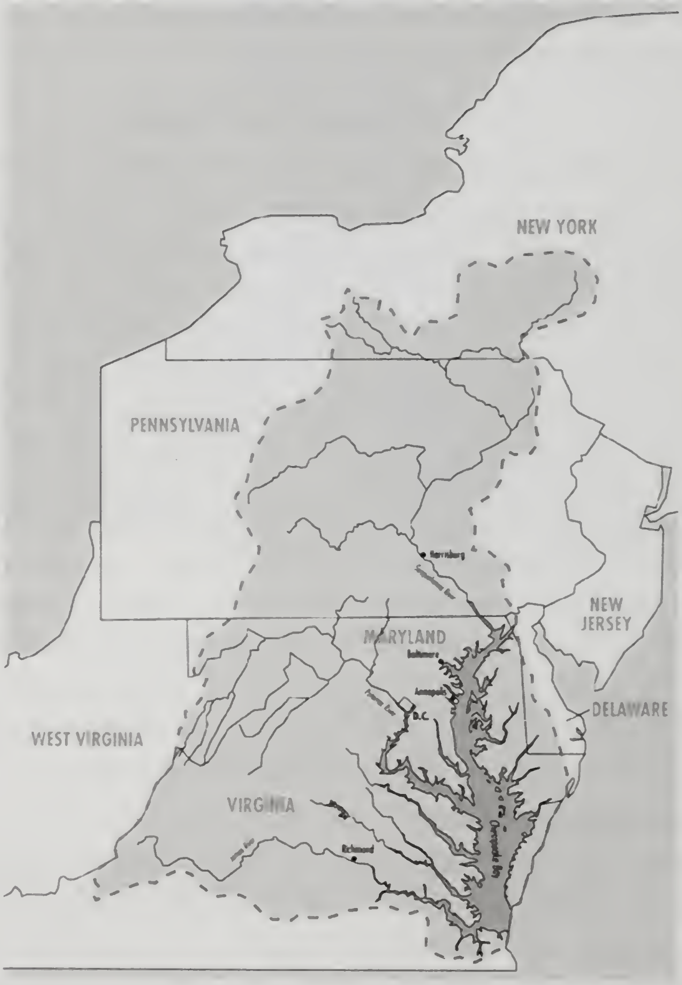
Challenges and Opportunities

Today, the Chesapeake Bay is experiencing rainwater-carried runoff from the watershed states, over-harvesting of marine life, invasion by foreign species, and dwindling seagrass. The pollution comes from excess nutrients in over-enriched agricultural fertilizer treatments and farm animal manure. The pollutants also include toxic runoff from metropolitan

[2] For this reason, The Nature Conservancy partners with NASA to perform migratory bird studies using state-of-the-art NPOL Doppler radar.

areas, including lawn fertilizers, septic systems, car exhaust, and similar type sources. These nutrients and pollutants fuel the growth of algae in the water. When algae die, they decompose in a process that depletes the water of oxygen which all aquatic species need to survive. Algae also block sunlight that healthy underwater bay grasses need to grow. In the 1970s, the bay was discovered to contain one of the planet's first identified marine "dead zones." The water in dead zones is so depleted of oxygen that it's unable to support marine life.

Figure 1. Chesapeake Bay watershed (courtesy Chesapeake Bay Foundation)



In the last 50 years, the bay's oyster population has been devastated by these problems. In the 1950s and '60s, diseases overtook those oysters that had not already been over-harvested since the 1800s.

The depletion of oysters has had an especially harmful effect on the bay's water quality because oysters serve as natural water filters. A single healthy oyster can filter 50 gallons of bay water a day!

Many organizations are now focused on restoring the bay's long-term health, especially the six university programs discussed here.

Eastern Shore Socio-Economics

The communities of the Eastern Shore are located in two offshore Virginia counties separated from the mainland and nine counties of Maryland's shoreline east of the Chesapeake Bay.[3] The region is east and southeast of the Washington, DC metro area, and is accessible from the Washington area by driving via the Chesapeake Bay Bridge.

The region is comprised of rural coastal communities that are culturally unique due to their marine heritage and natural resources. Many of these communities have ongoing concerns for the economic viability and social well-being of their year-round residents. In addition to the up-and-down fortunes of the commercial fishing and shellfish industries, there are concerns about maintaining the production of agricultural and livestock farms, particularly chicken farms which are major employers in the region, as there are estimated to be more than 9,800 poultry industry jobs on the Eastern Shore.[4] At the same time, these communities are concerned about the environmental integrity of the region, including the groundwater resources that supply fresh water to residents and industries.

Agencies and organizations in the region are working to expand eco-tourism and promote the region's maritime cultural heritage. There is a popular annual birding festival and an annual benefit festival based on the wild horses of Assateague Island.[5] Economic indicators show that the dollar flow from these events to local businesses has increased over recent decades, although the impact is mostly seasonal.

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[3]The offshore Virginia counties are: Northampton and Accomack. The Maryland counties can be subdivided into Lower Shore, Mid Shore, and Upper Shore. The Lower Shore counties are Somerset, Wicomico, and Worcester. The Mid Shore counties are Caroline, Dorchester, and Talbot. The Upper Shore counties are Cecil, Kent, and Queen Anne's. When these Maryland and Virginia counties are combined with counties in Delaware, the entire geographic region comprises the Delmarva Peninsula.

[4]Delmarva Poultry Industry, Inc. provides these data on Delaware, Maryland, and Virginia separately, and these statistics are based on Maryland and Virginia only.

[5]This event involves herding horses and thinning the herds by auctioning foals and fillies.

Efforts to establish an incubator-style Sustainable Technology Park on the southern tip of Virginia's Eastern Shore in the early 2000s did not survive. However, an industrial base has recently been growing around the federal facilities on Wallops Island in Virginia. These include a NASA flight center, NOAA data station, and Naval systems center. Workers at Wallops include around 1,000 full-time NASA civil service employees and contractors, 100 NOAA employees, and 30 Naval personnel. The related technology industry growth includes both on-site and off-site offices for the major government contractors, along with Wallops Research Park, Mid-Atlantic Regional Spaceport (promoting Virginia's commercial space industry), and the Virginia Space Flight Academy and Marine Science Consortium – which are attractions for kids and adults. Additional entities with similar purposes exist on the Maryland side of the border, along with a "Skipjack Network" website, which showcases enterprises that can help strengthen and diversify the economy of Maryland's Eastern Shore.

University-Based Research and Education

Due to the delicate and dynamic nature of the Eastern Shore, the region has become a hotbed of studies that relate, in some way, to the environment of the region. Several universities have important research and education programs in the area. They are: University of Virginia, Virginia Tech, William and Mary, and three of the twelve institutions comprising the University System of Maryland (USM) – University of Maryland-Eastern Shore, Salisbury University, and University of Maryland Center for Environmental Science. I briefly highlight each in geographical order beginning at the southern tip of the peninsula and heading north. This is not meant to be a comprehensive inventory of all facilities, research, and education & outreach – but rather some examples of activities and assets. The appendices provide additional background on some of the programs.

University of Virginia

The University of Virginia (UVA) Anheuser-Busch Coastal Research Center (ABCRC) is located on 42 acres in the harbor at Oyster, Virginia, on the southern end of the Eastern Shore. Researchers at ABCRC are studying sea level rise, storm effects, groundwater conditions, and the populations of fish, shellfish, vegetation, birds, and mammals. The facility is located within The Nature Conservancy's Virginia Coast Reserve. The Conservancy's shore office is about 20 miles north of Oyster

near Nassawadox. Several primary research sites within the coastal preserve are located along this north-south route.

Long-Term Research and Data

ABCRC serves as the home laboratory for the National Science Foundation (NSF)-supported Long-Term Ecological Research (LTER) program at the Virginia Coast Reserve (VCR). Long-term data provide the means to assess changes in climate, sea level rise, and land cover, which have significant consequences for all populations on Earth – human, animal, plant, and microbial. LTER scientists are able to predict future environmental conditions and new patterns in land and sea levels, forecast the rate and direction of change, and distinguish long-term trends from short-term changes.

VCR/LTER scientists have studied the changes in the VCR marshes from the 1950s to the present. The scientists collect data from meteorological stations, tide gauges, water level recorders, and other monitoring equipment. They use remote sensing satellite imagery and web camera photography. Wireless networks at the research sites provide access to Global Positioning System (GPS) latitudinal and longitudinal surveys necessary for creating Geographical Information System (GIS) maps. For example, shrub thicket and land use data are combined with other environmental data such as data on shellfish reefs, and all the data are entered into a long-term database for comparison purposes.

The project's main web site[6] is referred to as its "file cabinet," where the raw data are publicly accessible via a searchable online catalog.[7] The databank includes images such as time-series photos and webcams, and interactive maps.[8] For example, a map of Hog Island from 1852 can be overlaid onto a map of the island in 2012, or whatever year the user

[6]www.vcrlter.virginia.edu

[7]For immediate access, researchers can use the data access server searchable by keywords, research areas and sites; or, they can make a formal data request by completing a data license form indicating agreement with LTER acknowledgment policies.

[8]VCR/LTER publishes more than 130 datasets using standard ecological metadata language. In addition to the VCR/LTER web site, the data are available through several collaborative efforts to make long-term ecological data available, including the National LTERnet, NASA Mercury, and National Biological Information Infrastructure data catalogs. UVA and ABCRC also participate in the EcoTrends Project, primarily funded by NSF and the Agricultural Research Service, and which coordinates research across participating state and federal agencies and institutions.

chooses. The data also include field trip videos, researcher interviews,[9] dissertations and theses, and bibliographic listings. During the current 6-year funding cycle, more than 700,000 clients – users in more than 190 different countries or international organizations – have downloaded more than 5.1 terabytes of information via the data access portal.[10] In the same time period, some 175 books and articles have also been published.

LTER Education

The Schoolyard LTER (SLTER) program works extensively with high schools in Northampton County, a relatively poor Virginia county, and the impact of the program has been significant. SLTER has developed classes including a popular "Environmental Science II" course and some 200 students have performed activities similar to those performed by the professional scientists. SLTER provides the schools with water analysis kits, cameras, GPS units, computers, and taxonomic software. The students collect data to monitor water quality at a few dozen VCR sites, and enter their data into a long-term student database to identify changes. They describe their projects in multimedia presentations at semester's end.

Graduate training is considered a particularly important part of the LTER education mission, and each year about 20 students conduct research projects at the site. Some 30 master's theses and doctoral dissertations have been completed during the current funding cycle.

Virginia Tech

Virginia Tech's Eastern Shore Agricultural Research and Extension Center (ES-AREC) is located in Painter, Virginia, a mid-point between the two Virginia counties on the shore. The mission of ES-AREC is to support the sustainability of agricultural production on Virginia's Eastern Shore. The overall site is a 226-acre farm owned by Virginia Tech that includes an office complex, laboratories, equipment buildings, garages, greenhouse, cropland, graduate student housing, large freshwater pond, woodland areas, and farm manager's residence.

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[9] The video presentations are also available on educational and video sharing sites such as SciVee. See http://amazon.evsc.virginia.edu/video/scivee.html.

[10] The datasets formally requested by users filling out data license forms are an important indicator of impact. These users have made 860 requests during Phase V, including 300 from researchers not associated with VCR. An additional 187 datasets were requested by automated programs.

The graduate students conduct field, greenhouse, and laboratory research. A particularly important research area is soil management since Virginia is a watershed state for the bay. A main goal of this research is to reduce soil erosion and sedimentation into the bay, tributaries, and ocean. The Center accomplishes this through applied research, demonstrations, and education on conservation-oriented best management practices and on cover crops which are planted to keep nutrients from leaching. For better nutrient management, the Center is also testing innovative fertilizer sources that promote more efficient use and decrease environmental losses from runoff, as well as alternative application practices for fertilizers and fumigants.

Economic Impact

Each year, the ES-AREC staff and researchers grow about 30 rotational crops of regional importance for their studies (Table 1). They also evaluate alternative crops with potential economic significance.

Table 1. Crops grown for research at Virginia Tech's Eastern Shore Agricultural Research & Extension Center (ES-AREC)

ES-AREC research crops				
Alfalfa	Cotton	Lettuce	Soybeans	Tomatoes
Barley	Cucumbers	Lima beans	Spinach	Watermelon
Broccoli	Dry beans	Peppers	Squash	Wheat
Cabbage	Edamame	Potatoes	Sunflowers	Zucchini
Cantaloupe	Eggplant	Pumpkin	Sweet corn	
Collards	Field corn	Snap beans	Switchgrass	

For its potato crops, the center is researching nitrogen sources, application methods, russet potato production rates in Virginia, and tuber disease management. Virginia Tech oversees a weekly report called the Virginia Potato Disease Advisory[11] that advises potato growers on the likelihood of potato disease development. Based on the ES-AREC research, the Advisory makes recommendations for regional farmers on fungicides to address potato diseases. In 2010, Eastern Shore potato

[11]The advisory operates under the direction of Steve Rideout, Associate Professor of Plant Pathology, Physiology, and Weed Sciences at ES-AREC.

growers saved $300,000 by using recommendations from the Advisory to reduce fungicide applications.

Other research projects have direct applications to the industry and economy of the Eastern Shore, as well. For example, the chicken industry is a huge sector of the economy on the Eastern Shore where economic activity estimated to be in excess of $2.3 billion.[12] Consequently ES-AREC is testing organic fertilizer sources such as poultry litter for its environmental impact.

William and Mary

The College of William and Mary's Virginia Institute of Marine Science (VIMS) has its main complex near Williamsburg, Virginia, where the campus is located on the mainland side of the Chesapeake Bay. VIMS, chartered in 1940, hosts the William and Mary graduate school in marine science at this site – Gloucester Point on the York River.

VIMS also operates the Eastern Shore Lab (ESL) located on five acres in the seaside fishing village of Wachapreague, Virginia, where the resident researchers specialize in coastal ecology and aquaculture. In addition to its existing hatchery, ESL opened a unique and innovative new seawater facility in June 2012 next to Wachapreague Channel. It provides access to clean seawater with salinity levels comparable to the nearby ocean and allows researchers to raise marine organisms in conditions that are protected, yet similar to those of the open ocean. The building is state-of-the-art and designed to withstand rising seawater, as the exterior power supplies and light fixtures are more than 14 feet above sea level.

Seagrass Research and Restoration

For more than 15 years, ESL has been leading a project to reintroduce submerged vegetation (seagrass) into the VCR coastal bays.[13]

[12]Delmarva Poultry Industry, Inc. provides this data on Delaware, Maryland, and Virginia separately, and these statistics are based on Maryland and Virginia only.

[13]The seagrass restoration project is a long-term collaborative effort with VCR/LTER, The Nature Conservancy, and other partners. VCR/LTER, for example, is providing data such as water depth and lagoon bathymetry (measurements) and logistical support for Nature Conservancy volunteers. The project has been funded over time through federal, state, private, and foundation grants, including: NOAA, through the American Recovery and Reinvestment Act (ARRA); several Commonwealth of Virginia programs; The Nature Conservancy; U.S. Army Corps of Engineers; and private grants from corporations and foundations such as Allied-Signal Foundation, Norfolk-Southern, and

Seagrass plays an important role keeping the coastal bays clean as it absorbs sediment in the water and transforms the bare seafloor to grassy underwater meadows providing homes for shellfish and finfish. The seagrass restoration started in 1997, when ESL scientists began spreading rice-sized eelgrass seeds in the coastal bays after hearing an anecdotal report of a successful small eelgrass patch south of Hog Island Bay. From 1999 through 2010, the programs spread 41 million eelgrass seeds across 350 acres in four coastal bays. Through natural re-seeding, these plantings have now expanded into 4,200 acres of eelgrass meadows. This effort has been described as the world's largest and most successful seagrass restoration project.[14] Long-term studies by VCR/LTER confirm the eelgrass recovery, and modeling studies show that full restoration has not even been reached yet.[15] With the success of the seagrass restoration program, ESL was also able to re-introduce to the new underwater meadows about 2.5 million juvenile bay scallops reared at the ESL hatchery.

Shellfish Data and Industry Applications

As recently as 2005, consistent economic data has not been collected in Virginia for shellfish aquaculture – as distinct from traditional shellfish and fish "landings" (onto the shore or dock). USDA has collected economic data for farm crops and livestock since the 1860s[16] and NOAA similarly maintains statistics on commercial fish and shellfish landings.[17] The NOAA data show that commercial operators are continuing to land clams and oysters from the bay in the traditional way, although at diminished rates.

With NOAA support, every year since 2005, VIMS has surveyed Virginia clam and oyster aquaculture farmers on their market sales and employment to produce an annual report on the newly-emerging

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the Keith Campbell Foundation for the Environment. It is estimated that the NOAA ARRA funding provided 55 jobs in Virginia.

[14]This success story was recently featured in a series of 9 articles in a February 2012 specially-themed issue of the journal, *Marine Ecology Progress Series*, co-edited by the head of the VIMS/ESL seagrass restoration program, Professor Robert Orth.

[15]However, they also show that, over time, the grass will likely be negatively impacted by increases in water temperature predicted by current climate change models.

[16]See http://www.nass.usda.gov/About_NASS/Timeline/The_Founding_Period.

[17]See http://www.st.nmfs.noaa.gov/st1/commercial/index.html.

aquaculture sector.[18] These annual data are useful for determining industry trends, and are particularly useful for the Eastern Shore communities where many shellfish aquaculture operations are based. In recent years, Virginia aquaculture has been steadily growing and changing as new techniques are proven. The numbers show that the state's clam aquaculture industry remains the largest in the nation, producing 450 million clams worth $26 million in 2011. Oyster growers using aquaculture techniques sold more than 23 million oysters worth more than $6.7 million in 2011 – up 38% from 2010.

The aquaculture industry growth in Virginia can be attributed in part to ground-breaking research by VIMS and ESL which have become recognized for their research on the ecology of all shellfish – clams, oysters, and scallops. VIMS has introduced such innovations as: oysters grown in protective containers (cages, racks, and floats) which reduces predators; farmed oysters that are moved into saltier waters just prior to harvest, nearly eliminating the presence of bacteria that can make humans sick; and faster growing oysters.

Education and Outreach

VIMS maintains web sites of free resources for teachers: Bridge[19] is "an ocean of teacher-approved marine education resources," and "ChesSIE"[20] (Chesapeake Science on the Internet for Educators) provides science information about bay area animals, plants, habitats, and water as well as professional development opportunities in the watershed area.

University of Maryland-Eastern Shore

The University of Maryland Eastern Shore (UMES) is a historically-black university located in Princess Anne, 10 miles from the bay and 20 miles from the ocean. The university has top-rated research and education programs in marine and related disciplines, particularly

[18]The "Virginia Shellfish Aquaculture Situation and Outlook Report" is available from the VIMS website, www.vims.edu.

[19]http://web.vims.edu/bridge, sponsored by NOAA Sea Grant program and the National Marine Educators Association.

[20]http://www.bayeducation.net, a project of the Mid-Atlantic Marine Education Association.

fisheries science. UMES offers bachelors, masters, and PhD degrees in Marine, Estuarine, and Environmental Sciences (MEES).[21]

While there has been a recent increase in the number of students nationwide choosing marine science as careers, the percentage of minorities doing so is below expectations. The NOAA Educational Partnership program supports the UMES-led Living Marine Resources Cooperative Science Center (LMRCSC) consortium to increase the number and diversity of students involved in NOAA core science areas. The consortium includes six other universities located on the water around the country[22], which are linked via video-teleconferencing for distance-learning, enabling them to share classes and seminars by renowned scientists and foster research collaborations among the schools. The consortium was founded in 2001 when NOAA awarded UMES and its partners their first grant; support is currently extended through 2016.[23]

UMES has a water quality lab on campus and, in 2005, built a $3 million Paul S. Sarbanes Coastal Ecology Center located 30 minutes from the UMES main campus on 8 acres across from Assateague Island. This center is under the administrative authority of the UMES School of Agricultural and Natural Sciences, but also serves as a field lab for LMRCSC. It is focused on fish microbiology, water quality, and the ecology of water organisms.

LMRCSC research, overall, is focused on the four broad areas of fish populations, economics, habitats, and aquaculture. The consortium conducts an annual proposal solicitation with guidance on the priority research topics for the year for the purpose of encouraging collaborative research among the students, faculty, and NOAA scientists.

Program Outputs and Benefits

Since 2001, the LMRCSC consortium has produced significant output measures of its performance, as shown on Table 2. The data reflect

[21]Areas of specialization for the MEES academic program are: fisheries science, oceanography, ecology, environmental chemistry, environmental science, and environmental molecular biology/ biotechnology.

[22]The partner institutions are: Delaware State University, Hampton University, University of Maryland, Savannah State University, University of Miami, and Oregon State University.

[23]In 2006, NOAA awarded the consortium a second 5-year grant and, at the beginning of FY2012, awarded approximately $15 million, extending support through 2016.

more than 350 graduates, 80 research projects, 150 interns, 500 presentations, nine government and university scientists, and 1,085 trainees. The consortium works to support NOAA's mission to conserve, protect and manage fish stocks. Its research has resulted in information on more than twenty species, including, for example, the mortality of yellowtail flounder; the genetic structure of monkfish; and the socioeconomic indicators of billfish. The ongoing research is also providing information needed to restore and enhance fish habitats.

Table 2. LMRCSC Output Measures

Education	LMRCSC institutions graduated 352 students (268 bachelors, 73 masters, and 11 PhD), with 55 students participating in open ocean fisheries research through winter cruises
Research	The LMRCSC consortium supported more than 80 research projects developed in collaboration with NOAA scientists
Internships	The consortium has provided internships for some 150 students at NOAA labs or at the University of Maryland Institute of Marine and Environmental Technology
Presentations	LMRCSC research resulted in more than 500 presentations at meetings of scientific and professional societies, and 185 peer-reviewed articles and book chapters
Employment	These outputs have resulted in at least 3 NOAA hires, 3 university faculty members, and 3 post-doctoral researchers
Outreach	The consortium has provided other training and support for an additional 1,085 graduate, undergraduate and K-12 students

Establishing the consortium has allowed the UMES faculty to leverage more than $11 million in grant funding from other agencies to establish related programs. The new programs have enabled UMES to further develop capacity in marine and fisheries science and recruit more graduate students. Through one of these programs, the university was able to add a Professional Science Masters (PSM) degree in Quantitative Fisheries and Resource Economics.

Salisbury University

As of September 2012, 677 university presidents had signed the American College and University Presidents' Climate Commitment (ACUPCC), a group of academic institutions pledging to work towards climate neutrality. The commitment is the first of its kind to target climate

neutrality, not just a reduction. The signers include Salisbury University and the eleven other institutions comprising the University System of Maryland.

Salisbury University (SU) is the largest institution of higher education on the Eastern Shore. Located in the city of Salisbury, Maryland, the campus occupies 155 acres, and includes 56 buildings with more than 1.6 million square feet of space. Salisbury signed on to the ACUPCC commitment in 2007, and that commitment states:

> "We believe colleges and universities must exercise leadership in their communities and throughout society by modeling ways to minimize global warming emissions, and by providing the knowledge and the educated graduates to achieve climate neutrality."

Almost 470 of the institutions signing the Commitment have completed Climate Action Plans which outline how and when they will achieve climate neutrality, or zero net greenhouse gas (GHG) emissions. Salisbury University developed its plan in 2010 through a workgroup of some twenty students, faculty, and staff. The focus of the SU Plan is to reduce emissions through: efficiencies of operation/equipment; increased use of renewable energy; and promoting behavioral changes. For most of the ACUPCC signers, including Salisbury, the target date for achieving neutrality is 2050.

In order to provide a baseline to track its progress toward neutrality,[24] the university developed a campus-wide GHG inventory or "carbon footprint" according to ACUPCC standards, published in early 2009. The University System of Maryland was the second university system in the country to require its campuses to conduct carbon inventories,[25] and SU has been the only institution in the Maryland system to conduct its inventory using its own students exclusively. Students in SU's Perdue School of Business conducted the inventory, collecting data from a number of sources including, for example, commuter data from a

[24]For tracking this progress, the university actually identified FY2005 as its baseline year (rather than the 2008 data), since statewide energy reduction requirements use 2005 as the baseline year. Therefore, a retrospective carbon footprint inventory was developed for 2005 by estimating data based on population and other changes. Going forward, the university intends to conduct carbon emission inventories every other year.

[25]California was first.

survey of 1,142 respondents out of the overall campus population of approximately 9,000.[26]

Education and Curriculum

SU has three undergraduate degree programs related to the environment, climate change, and sustainability: (1) an Environmental Studies major or minor; (2) a Department of Biological Sciences dual major in biology and environmental/ marine science (in cooperation with UMES); and (3) a Geography and Geosciences major, with tracks in environmental land use planning and Earth & atmospheric science. Although SU does not currently offer a graduate program in environmental studies, it offers an MS in Applied Biology which provides training in biotech lab research and environmental sciences. Sustainability is continually being integrated into the academic programs at the university, and at least 87 courses from 19 disciplines now include a focus on the environment.

In July 2012, SU elevated its fast-growing interdisciplinary Environmental Studies program to become the Department of Environmental Studies. In this academic area, the students learn from distinguished faculty such as award-winning Chesapeake Bay writer Tom Horton, and Jay Martin who started Community-Sponsored Agriculture on the Eastern Shore. The students intern at state and federal agencies such as the U.S. Environmental Protection Agency (EPA); during the past three years, five environmental studies majors have been awarded prestigious $50,000 EPA Greater Research Opportunity Fellowships. The students work toward career paths in: (1) land/resource management, (2) pollution control/abatement, (3) environmental advocacy, (4) eco-tourism/ environmental education, (5) sustainable business, or (6) graduate school or law school, including environmental law.

SU also provides the students opportunities to learn about the environment and sustainability by living in a "Green Floor Living-Learning Community" in one of the dormitories. This option is open to first-year students who take certain courses, perform green service projects, and develop environmentally-oriented activities on campus. As extra-curricular activities, students can cultivate the campus garden or kayak on 100,000 acres of local rivers and wetlands, among other activities. In addition, the university has a number of university-sponsored

[26]The 2008 GHG inventory, filed with ACUPCC, documents the student survey work toward the inventory. See http://rs.acupcc.org/ghg/645/.

clubs focused on the environment such as the Environmental Student Association, Bio Environs Club, and others.

Research and Community Service

A wide variety of environmental research is pursued on the Salisbury campus. Environmental Studies faculty members have received grant funding from NSF, The Nature Conservancy, and other sources to study forest growth locally and in the Amazon, and this has led to more than 20 published articles. The SU Biological Sciences Department is performing ongoing research in its Bacterial Source Tracking Laboratory and conducting research on biofuels. The Geography/Geosciences Department is doing research on smart growth, and the Sociology Department is researching local sustainable agriculture. Based on conference agendas and other sources,[27] a number of research topics are pursued at SU that closely relate to the Eastern Shore marine environment.[28]

The Salisbury University-based Eastern Shore Regional GIS Cooperative (ESRGC) is a joint effort between the university and two regional planning and development councils covering six Eastern Shore counties.[29] The Maryland Department of the Environment recently hired ESRGC researchers to pinpoint 420,000 septic systems statewide in order to identify failing systems which critically impact the bay.[30]

University of Maryland Center for Environmental Science

The University of Maryland Center for Environmental Science (UMCES) is the University System of Maryland's environmental research institution. UMCES operates five programs, four of them being major

[27]See, for example, SU's annual Student Research Conference (which showcases and celebrates more than 200 student accomplishments), the 2011 National Conference on Undergraduate Research (held in Ithaca, New York), and the 2011 SU faculty grant proposals.

[28]A sampling includes: "The Chesapeake Bay and Puget Sound: A Bi-Coastal Survey of Environmental Issues and Perceptions"; "The Maryland Watershed Implementation Plan: What's Being Neglected in the Chesapeake Bay Clean-Up Efforts"; and "A Geographic Analysis of Storm Water Run-off as a Problem."

[29]These are the Tri-County Council for the Lower Eastern Shore of Maryland, and the Mid-Shore Regional Council.

[30]Current ESRGC projects involve a flood vulnerability analysis and critical area boundary mapping for the participating local and regional entities.

research facilities related to the environment in the Chesapeake Bay and Eastern Shore area: the Horn Point Laboratory (HPL) on the Eastern Shore; Chesapeake Biological Laboratory (CBL) at Solomon's Island on the western shore of the bay; Institute of Marine and Environmental Technology (IMET) in Baltimore; and the Appalachian Laboratory in western Maryland, focused on the bay's watershed rivers and streams. UMCES also administers the Maryland Sea Grant College program out of College Park, Maryland, which is a university-based cooperative research and education extension program.

In general, the UCMES sites are focused on ecosystem-based environmental management – integrating marine, aquatic, and terrestrial habitats – and ecosystem restoration, which involves holistically restoring sustainability to areas stressed by development and climate change. Every year more than 100 graduate students conduct research and studies at UMCES as part of the University of Maryland's MEES program, mentioned earlier.[31] The UMCES faculty and students frequently use scuba diving as a research tool. They also use the research vessels, and the flagship of that fleet is the 81-foot R/V *Rachel Carson.*

The Center administration of UMCES is headquartered at the Horn Point Laboratory on more than 800 acres by the Choptank River – the former estate of Francis V. DuPont – near the city of Cambridge on Maryland's Eastern Shore. HPL began operation in 1974 after Hurricane Agnes rainfall decreased the bay's water salinity levels in 1972, drastically diminishing shellfish populations. HPL focuses on environmentally-sustainable strategies for restoring the bay, its watershed, and the mid-Atlantic coastal ocean, and the HPL scientists have made significant research findings related to the bay's dead zones and acid levels.

Oyster Aquaculture

HPL has one of the largest oyster hatcheries on the East Coast, the Aquaculture and Restoration Ecology Lab. This $25 million 65,000 square foot aquaculture facility, with its sophisticated instrumentation, is designed to produce disease-free oyster larvae and "spat" (baby oysters produced by allowing oyster larvae to settle on old oyster shells in tanks). The spat is used in research, educational projects, the private aquaculture industry, and restoration activities throughout the Maryland portion of the bay. In this way, HPL serves a similar purpose for oysters as a state

[31]Lab instruction takes place at the UMCES sites, and the degrees are awarded by the University of Maryland.

agricultural experiment station does for crops. The spat, or seed oysters, are planted in the bay, producing clumps of oysters that grow and can later be harvested.

Unique features of the aquaculture facility include experimental controls for climate change research; a quarantine facility for the safe study of non-indigenous species; and a narrow water channel for research on submerged vegetation and seagrass. The quarantine lab and ¼-acre outdoor ponds are supplied with up to 350 gallons per minute of Choptank River water.

By the Fall 2012, HPL has produced a record number of oysters to aid in restoring the bay. This is the fifth year in a row that production has exceeded half a billion, as the hatchery has already produced more than 880 million spat in 2012. Over the past decade, the HPL hatchery has deployed more than 4.5 billion young oysters to the bay.

Oceanography

HPL scientists are also very active in interdisciplinary oceanography and its monitoring instruments, and they have developed several new technologies for accomplishing their research activities:

- The *physical* oceanographers are concerned with the motion of the ocean – waves, erosion, and interaction with climate variability – as well as systems and technologies for environmental observation. UMCES helps run a NOAA-funded public-private partnership to test new sensor platforms.[32]
- HPL's *chemical* oceanographers have expertise in water columns and sediment, and they are developing a new technology – an integrated water column profiler – which can observe simultaneously water properties such as turbulence, particles, and nutrient uptake.
- The HPL *biological* oceanography group is concerned with food web dynamics and specializes in shellfish, aquatic plants, and floating plants and animals – including jellyfish and unicellular organisms.

HPL's overall strength is in collaborative *biogeochemical* studies, including, for example, the modeling and ecology of seagrass beds.

[32]The UMCES/CBL site serves as the headquarters for the Alliance for Coastal Technologies (ACT), a NOAA-funded partnership of universities, companies, and state programs which together serve as a testbed for quantitatively evaluating new sensor platforms. In early 2013, a 16-foot long underwater research vehicle will be delivered to UMCES which will provide even more data collection capabilities.

Education, Outreach, and Extension

UMCES reaches more than 12,000 school age students and 50 teachers annually, helping school districts comply with state environmental education requirements. HPL's Environmental Science Education Center is for K-12 education and teacher training focused on STEM subjects. HPL offers a variety of programs for school age students. For example, the "Biologist for a Day" program brings groups of middle and high school students for a day of hands-on learning at the hatchery. Eastern Shore middle school students have helped to hatch and raise baby diamondback terrapins (the state reptile) and then release them into HPL-monitored wetlands. For even younger children, HPL offers brief weekday tours so they can see baby oysters spawn.

UMCES and HPL extension activities are coordinated through the University of Maryland Extension and Sea Grant programs. They involve technical support via training, publications, and site visits for a variety of stakeholders – from home owners to industry. For example, HPL is evaluating the effectiveness of aquatic plants (a $2 million industry in the state) for their value in keeping algae out of the tens of thousands of stormwater ponds in residential developments. HPL extension, in turn, is sharing the research results so the ponds can be better managed.

HPL conducts extensive public outreach. In addition to twice-weekly walking tours during summer months, the lab also holds an annual open house in the Fall with numerous activities and exhibits. The open house begins with a "Spat Dash" race to benefit environmental education programs and raises thousands of dollars for summer student scholarships.

Commonalities Among the University Programs

Several unique aspects of each Eastern Shore university environmental program were highlighted above. While they represent different institutions and states, the programs also have much in common. The following list suggests some of the more generic aspects of the educational missions of these university programs. Most of these institutions:

- Host visiting scientists on contracts and grants from other universities in the spring and summer months, and maintain facilities to accommodate them (*e.g.*, dormitories and dining halls). They even maintain boats to transport them to and from data monitoring locations.

- Receive supplemental funding from the National Science Foundation's Research Experience for Undergraduates program and other programs to provide paid summer fellowships, grants, and internships. These types of programs allow undergraduates to conduct research with mentors, and they may be paid monthly stipends, and lodging and travel expenses.

- Offer courses at the undergraduate and graduate levels taught by the resident faculty and principal investigators. The courses may even be taught toward academic degrees granted by other universities. The resident faculty members also supervise the research of rotating graduate researchers, and may serve on policy advisory boards needing specialized expertise.

- Provide teacher training in STEM areas for local high school and middle school teachers. This may be delivered in the form of lectures, group discussions, outdoor excursions, lesson plans, videos of scientist interviews, and other media.

- Offer paid summer internships for local high school students during the summer months. Some of these programs are competitive and merit-based, and the hope is that the hands-on research will encourage the students to pursue eventual majors and careers in environmental studies.

- Produce publications, data, conference presentations, patents, and intellectual capital resulting from the research that is likely accessible for second-level applications or licensing.

- Host multiple school student field trips and tour groups representing various professional societies (*e.g.*, Virginia Master Naturalists).

- Conduct monthly evening seminars to educate the public on research findings and environmental projects on the Eastern Shore. Topics include, for example, the bay's dead zones, the impact of climate change on the Eastern Shore, and the overall ecology of the region. They also maintain speakers' bureaus for local civic organizations seeking speakers with expertise in environmental subjects.

- Provide extensive research and academic facilities such as classroom buildings, teaching laboratories, wet laboratories, conference centers, libraries, high-speed Internet, GIS, laboratory equipment, image analysis capabilities, centralized data portals and database systems, video equipment, and museums and exhibit/display areas.

- Maintain research fleets with small vessels for local project work and shallow-water habitats, and larger vessels for offshore work and open ocean navigation.

- Support resident staff providing specialized technical services to the onsite and visiting researchers, such as assistance with computers, graphics, equipment, mechanics, chemical analyses, and even water transportation.

See the Appendices for additional background on several of the university programs.

Rationale for Promoting a Science and Technology Sector

Clearly, there is a variety of university-based education and research programs on the Eastern Shore with a similar variety of facilities and expertise in environmental fields. Due to the fragile nature of the environmental conditions of the region, and environmental connections to the regional economy, each of the programs provides unique opportunities for education, research, internships, employment, and community involvement. The outputs, impacts, and research findings of the programs indicate they are fulfilling their missions, making exceptional research contributions, and providing a service to their stakeholders regionally, nationally, and internationally. Furthermore, the researchers involved in complementary research efforts seem to be cooperating well toward their common goals.

Given these findings, it's interesting to note that a 130-page Eastern Shore Career Guide describes 123 occupations listed as appropriate for Maryland's Lower Shore and Upper Shore[33] but the guidebook does not list any positions related to marine science and technology, for example. This is a notable omission, particularly given that it lists "fishers and related fishing workers" as occupational groups with the fastest nationwide growth rates (from 2004 to 2014).[34]

[33]In this guidebook, "Lower Shore" includes Somerset, Wicomico, and Worcester counties; "Upper Shore" includes Caroline, Dorchester, Kent, Queen Anne's, and Talbot counties.

[34]At the time it was printed, the *Career Guide* projected that there were 30,955 openings on the Eastern Shore for 121 of the 123 occupations (data on projected number of biologists and chemists was listed as "not available.")

Occupations based on science and information rather than manual labor make up the "knowledge industry sector."[35] This sector – which includes marine science, sustainable agriculture, and environmental studies among others – is growing faster than the overall economy and it supports higher salaries.[36] Knowledge-based economies tend to feature regional innovation systems clustered around science and technology facilities. Innovation clusters are comprised of tech firms, university spinoffs, entrepreneurs and their start-ups, and the technical support organizations that serve them – usually a variety of for-profits and non-profit centers that can capitalize on the region's scientific resources.

An internationally-recognized example not far from the Eastern Shore is the biomedical corridor in the Baltimore area extending from Johns Hopkins University down to the National Institutes of Health in Bethesda, Maryland.

Is there a sufficient science and technology base on the Eastern Shore on which to build a science and technology-based economy? There is a concentration of research and education on environmental issues and an existing cadre of world-class scientists doing basic and applied research and producing outputs like scientific and technical information, scholarly publications, technology applications, patents, *etc*. Furthermore, local human resources are being developed through the educational programs and internships to create an available pool of human capital – although it has been said that the Eastern Shore suffers from brain drain, according to a member of the Greater Salisbury Committee,[37] so there may be a need for incentives and programs encouraging them to stay.

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[35]The *Career Guide* contains three occupational clusters oriented toward scientific and technical fields: biologists, chemists, and engineers. It lists these occupations related to the biology cluster: foresters, oceanographers, pathologists, range managers, and soil scientists. Related occupations for chemists are listed as: agricultural scientist, chemical engineer, chemical technologist, and food technologist.

[36]There is an extensive body of literature on technology-based economic development and regional innovation clusters. See, for example, www.clustermapping.us, a project under development at Harvard University and supported by the U.S. Department of Commerce, to be expanded in the Spring of 2013.

[37]Rafael Correa, President of MaTech, Inc., a former 8(a) company; presentation at the Federal Laboratory Consortium's Eastern Shore Economic Development Meeting, March 12, 2008.

"Collaboration between business and academia helps fuel research necessary for American innovation and helps prepare a workforce that meets the needs of industry. Both are critical components to future economic prosperity and job growth," as stated by the chairman House Subcommittee on Research and Science Education chairman at an August 2012 Congressional hearing.[38] What is needed on the Eastern Shore is an active focus on bringing together the public and private actors so that the networking and university-industry partnerships are not just clustered around Williamsburg, Charlottesville, Blacksburg, and College Park.

As an example, William and Mary's Virginia Institute of Marine Science has a VIMS-Industry Partnership Committee to advise the VIMS director on the development of long-term partnerships with industry and steps to improve collaborative research and technology transfer. In addition to representatives from William and Mary and VIMS, the committee includes industry participants from a few dozen companies, county economic development directors, representatives of NASA and the Office of Naval Research, and representatives from the Hampton Roads Research Partnership. This industry partnership has focused, for example, on marine sensors, the deployment of observation platforms in the bay, autonomous underwater vehicles, modeling and simulation of storm surges, and the Chesapeake Bay algae project which is researching the conversion of algae into fuels. Furthermore, the partners have collaborated on Small Business Innovation Research projects and federal, state, and international contracts and grants.

The above example is based on the mainland, but there are networks located on the Eastern Shore. The "Skipjack Network" website, mentioned earlier, was created to showcase enterprises that can help strengthen and diversify the economy of Maryland's Eastern Shore. This is an outreach activity provided by the University of Maryland-Eastern Shore, and it has received support from various sources like USDA's Rural Business-Cooperative Service, the U.S. Economic Development Administration, and Maryland Cooperative Extension. Skipjack is a website[39] that serves as a portal to local economic development directors and private business developers and intermediaries.

[38] August 1, 2012 hearing on Business-Research University Partnerships held by the U.S. House of Representatives Committee on Science, Space and Technology (Research and Science Education Subcommittee).

[39] http://skipjacknews.net/

Just as Maryland has its biomedical cluster, the Eastern Shore can become branded as a regional cluster of science and technology based on the environment. A commitment is necessary from all sectors – government, universities, and industry – to leverage the region's strengths. The following list of ten stakeholder groups notes some roles for each:

1. The university players: University faculty, researchers and administrators, technology transfer program staff, and community college faculty[40] can market their technologies and foster spinoffs and entrepreneurship through incubators, research parks, and business advice.

2. High-profile industry and growing technology companies: The existing base of recognized and well-known Wallops Island support contractors can sponsor networking events and bring visibility to the region's science and technology assets.

3. World-class federal laboratories: A NOAA laboratory on the Eastern Shore in Oxford, Maryland – an 18,000-square feet research facility on the water – houses the most complete expertise that exists worldwide on marine genomics, marine toxins, and harmful algae. Among the lab's commercialization applications, for example, is an aquaculture shrimp vaccine. The Smithsonian Institution will also soon be launching a research site in Edgewater, Maryland, for studying the coastal ecosystem. By law, federal scientific labs must promote tech transfer, and can enter into cooperative research and development agreements with partners for this purpose.[41] Some also offer technical assistance to small businesses. In addition to the NOAA Oxford Laboratory and Smithsonian, these mandates also apply to federally-funded research and development facilities at Wallops Island (NASA, NOAA, and Navy).

4. Professional societies and intermediaries: These players can organize conference sessions targeted toward Eastern Shore students and workers. As an example, the Washington Academy of Sciences in the Washington DC area recently teamed with Salisbury University and the

[40]For example, the Eastern Shore Community College (ESCC) started out as the University of Virginia Eastern Shore Branch on Wallops Island. In 1971, the UVA branch campus became an independent college within the state's system of community colleges, and moved from Wallops Island to Melfa, Virginia, in 1974. ESCC currently has an enrollment of more than 1,000 students.

[41]Stevenson-Wydler Technology Innovation Act of 1980 and subsequent related legislation.

Marine Technology Society to co-sponsor a career-related event for students.[42]

5. Technology councils: The Lower Eastern Shore Regional Technology Council is based in Salisbury, Maryland. The two counties of Virginia's Eastern Shore come under the purview of a regional technology council on the mainland known as Technology Hampton Roads. These types of groups provide a comfortable platform through which the public and private sectors can interact, but they must be conveniently-located on the Eastern Shore to be viable contributors.

6. Elected officials and economic developers: This group of stakeholders brings leadership and expertise in strategizing for technology-based economic development.

7. K-12 educators in STEM (science, technology, engineering and math) and locally-based **workforce organizations**: Teachers on the Eastern Shore, who are already benefitting from the locally-based academic and research programs, serve as mentors and advisors for the young interns and future workers.

8. Foundations and non-profits: The Chesapeake Bay Foundation is exemplary here, with a long history of environmental activism and educational programs in the region. The Foundation's legislative efforts have led to requirements for environmental education at the high school level to prepare students for green jobs and improving environmental awareness; also, the Foundation's vice president for education serves as director for the No Child Left Inside Coalition, a national coalition of more than 2,000 business and education groups.

9. Entrepreneurs: The UMES Sarbanes Coastal Ecology Center serves as a business incubation facility for entrepreneurs partnering with the university's Rural Development Center through the Worcester County Department of Economic Development. These entrepreneurs are potential users of university technologies and serve as role models for others.

10. Financial institutions and investors:[43] They provide needed capital for new ventures.

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[42] Capital Science 2012 Program: http://www.washacadsci.org/capsci12/abstracts.pdf.

[43] Such as Angel investors or venture capital -- to the extent that these communities are available within the region.

This region – with its unique environment and socio-economics – deserves an organizational champion to harness the attention of all these groups that have a stake in the region's future. The region will benefit from a targeted coordinated effort to develop an environmentally-oriented cluster, persistently over time. Regular and ongoing outreach is how relationships and collaborations develop. Such an approach, along with a strategy for environmental "branding," will result in positive economic impact. Toward this end, the Eastern Shore stakeholders are advised to study the best practices of other environmental clusters around the country, as well as international models. The possibilities are definitely not saturated at this point.

Appendix A: University of Virginia – Supplementary Information

UVA's Department of Environmental Sciences in Charlottesville, Virginia, serves as the administrative headquarters for the VCR/LTER project. NSF has supported this effort since the 1980s, as shown on Table 3. It is one of 26 such sites coordinated by the U.S. LTER Network encompassing more than 1,800 researchers. The data developed at VCR are integrated with data from other sites and programs -- including socio-economic data. The VCR/LTER studies have contributed to, for example, interdisciplinary breakthroughs involving social scientists in network analysis and ecology.[44] Data produced by the LTER program feeds into the U.S. Global Change Research Program which integrates research from 13 agencies.[45] A related global network, the International LTER program, is contributing to the United Nations program on assessing global change.

Many partners are on-site and have a stake in the research at the UVA field site. NOAA installed a Climate Reference Network station at this facility, providing adjunct data to the LTER meteorological data. The Nature Conservancy purchases related LiDAR[46] data for the Eastern

[44]For example, a collaboration with Dr. Stephen Swallow, a University of Rhode Island economist, has produced ground-breaking work on the tradeoffs involved in environmental conservation. A sample of this body of work is a presentation to the 2010 Soil & Water Conservation Society conference, "Selling Ecosystem Services as Public Goods to Consumer-Beneficiaries: An Auction Experiment on Restoration of Seagrass and Bird Habitat in Virginia Coastal Reserve."

[45]USGCRP began as a presidential initiative in 1989, and was mandated by Congress in 1990. From 2002-2008, it was known as the U.S. Climate Change Science Program.

[46]LiDAR = Light Detection and Ranging, an optical remote sensing technology.

Shore. Additional federal partners include the U.S. Geological Survey and the Naval Research Laboratory. Both federal and state agencies charged with managing coastal resources and/or agricultural fertilization practices benefit from data on the relationship between land use, water quality, and contaminants.[47]

Appendix B: University of Maryland-Eastern Shore - Supplementary Information

UMES has the advantage of being located in close proximity to Delaware State University (DSU) on the Delmarva Peninsula and Hampton University (HU) located near the mouth of the Chesapeake Bay, both historically-black universities and known for their programs in this area. For example, HU has a number of programs promoting the participation of minority students in marine sciences, including Multicultural-students At Sea Together (known as "MAST") and others. The DSU Aquaculture Research and Demonstration Facility has numerous freshwater ponds and large wet lab. UMES also collaborates with nearby sites of the University of Maryland's Center for Environmental Science; the LMRCSC partner is the joint USM Institute of Marine and Environmental Technology located on the Inner Harbor by Baltimore.

Appendix C: Salisbury University – Supplementary Information

The students inventorying the Salisbury University GHG emissions, found that the university emitted almost 28,000 metric tons of equivalent carbon dioxide (CO2) emissions during FY2008, as detailed on Table 4.[48]

Campus Milestones: ACUPCC participants commit to initiating at least two "tangible actions" toward carbon neutrality. Salisbury University's first commitment is focused on energy efficiency and conservation. The university established a policy that new campus construction and major renovations will be built to at least the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) Silver standard or equivalent certification. SU also plans for new construction to use 20-30% renewable energy, with the renewable energy

[47]These include the Water Conservation Districts on the Eastern Shore and the Virginia Department of Environmental Quality, among others.

[48]This is roughly equivalent to the annual emissions from 4,600 cars or sequestered by 7,600 acres of Maryland's Eastern Shore forest, according to the university's Climate Action Plan.

being generated on-site. The university has made significant progress in this regard. In 2008, the SU Teacher Education and Technology Center became the Eastern Shore's first LEED-certified new construction, earning Silver status. Since then, five more university buildings earned LEED certification, with two of them earning Gold certification. Since 2010, three buildings have been renovated with geothermal heating and cooling systems, which save 30-70% on monthly utility bills. One of the buildings features a roof-mounted solar water heater supplying hot water.

Table 4. SU Greenhouse Gas Inventory (2008) *does not total due to rounding

Source	Metric tons of equivalent CO2 emitted	Percentages
Electricity	15,525	55.6%
Oil & gas heat	3,551	12.7%
Ground transportation	5,753	20.7%
Air transportation	2,224	8.0%
Refrigerants, chemicals	708	2.5%
Solid waste	166	.0001%
Agriculture	8	N/A
Total	**27,935**	**~ 100%***

As its second commitment, SU has adopted an energy-efficient appliance purchasing policy. The washers and dryers in all the SU residence halls are now Energy Star-rated high-efficiency laundry units from Mac-Gray Intelligent Laundry Systems. SU was the first university in the country to install such units campus-wide. The washers use 12.2 gallons/wash, a savings of three gallons compared to previous machines, resulting in an annual savings of more than 100,000 gallons of water.

The campus vehicles and computers are also contributing energy efficiencies. The Motor Pool has replaced some of its older higher-mileage vehicles with more environment-friendly hybrid cars. A ride-sharing program is reducing the number of student, faculty and staff cars travelling to campus or home for weekends. The university's Information Technology office is using "server virtualization" software that reduces the number of physical server boxes that are necessary, saving both electricity and heating and cooling costs.

Even before signing ACUPCC and developing its Climate Action Plan, Salisbury University had a highly visible university-wide "Sustainability Initiative."[49] The university established a partnership with Pepco Energy Services to put into place campus-wide energy conservation measures projecting more than $5.3 million in savings by 2021. For example, lighting, plumbing and HVAC fixtures have been replaced with energy-efficient models.[50]

SU has been implementing a recycling program since about 1990, and every year exceeds the state standard which requires that it recycle at least 20% of its trash.[51] Since Spring semester 2012, the university has been composting food waste to minimize the volume sent to local landfills. The composting program has already processed nearly 70 tons of food waste which represents a decrease of nearly 60% in landfill use. The waste is compressed into fertilizer pellets sold to area farmers and also used in the campus greenhouses.

Campus Culture: SU has a tree-friendly campus, which is a national arboretum and home to student-planted wildlife and rain and vegetable gardens. This has garnered the university some recognition. It earned the 2009 Maryland Department of Natural Resources' (DNR) "People Loving and Nurturing Trees" (PLANT) Green award, the highest sustainability award given by the DNR Forest Service and Forestry Council. SU also became the first university to be honored with the WMDT News-Mountaire Environmental Star award. In 2010, 2011, and 2012, The Princeton Review named SU one of the nation's most environmentally-responsible colleges based on a survey and "green rating" scores of hundreds of colleges nationwide.[52]

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[49]Salisbury University touts this definition of sustainability "… meet the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland Commission, 1987).

[50]It is estimated the Pepco partnership will save an amount of electricity equal to powering 1,600 homes, and reduce emissions equal to removing 1,571 cars from the road or planting 2,145 acres of trees.

[51]The university's Climate Action Plan says SU "boasts a recycling program that consistently achieves a recycling percent higher than the required 20 percent mandated by the [1988] Maryland Recycling Act," but does not cite a percentage. The university website states "SU always far exceeds this standard."

[52]SU received a rating of 86 (on a scale of 60-99) in 2012, and was featured in the *Guide to 322 Green Colleges*.

An extensive web site, "Sustainability @ SU,"[53] consolidates an array of Salisbury University initiatives not covered here. Through its initiatives, the university intends to serve as a model for the surrounding regional community. Additional activities are in the planning stages, and will become visible to the region's residents in the near future.[54]

Bibliography

Boesch, D., Editor. Global Warming and the Free State: Comprehensive Assessment of Climate Change Impacts in Maryland. Report to the Maryland Commission on Climate Change from the Scientific and Technical Working Group, July 2008.

Christian, R.R., *et al.* "Ecosystem Health Indexed through Networks of Nitrogen Cycling" in *Coastal Lagoons: Critical Habitats of Environmental Change,* edited by M. Kennish and H. Paerl. New York: CRC Press. 2010, p. 17-42.

Codispoti, L. "Interesting Times for Nitrous Oxide," *Science*, March 12, 2010, p. 1339-1340.

Davis, L. "Saving the Amazing Red Knot from Extinction." *Virginia Tech Research.* Winter 2012, p. 32-37.

Eastern Shore Environmental Education Council. *Conservation Education Directory: A Resource Guide for Educators on the Eastern Shore of Virginia.* Eastern Shore Soil and Water Conservation District. 2009 Edition.

Environmental, Bioproducts and Robotics References: Environmental Programs & Projects in the Mid-Atlantic Region. Federal Laboratory Consortium Mid-Atlantic Region Eastern Shore Meeting, Meeting Handout, January 29, 2009.

Environmental Studies Department, Salisbury University Fact Sheet, undated.

Long-Term Drivers, State Change and Disturbance on the Virginia Coast Reserve: LTER V. Annual Report submitted to National Science Foundation by K. McGlathery and J. Porter, Co-Principal Investigators, September 16, 2011.

Lower Shore Workforce Alliance. *Eastern Shore Career Guide: A Premier Source for Career Information on the Eastern Shore of Maryland.* 2nd Edition, Fall 2008.

"Marine-Fisheries Science Center Secures New Federal Grant," University of Maryland Eastern Shore Press Release, October 21, 2011.

McNaul, A.D. "Research and Science Education Subcommittee Discusses Business-Research University Partnerships." *FYI, The AIP Bulletin of Science Policy News*, American Institute of Physics, Number 113, August 30, 2012.

McNey, R. "Federal Lab Representatives Visit Easton to Discuss Tech Opportunities," *The Star Democrat*, March 19, 2008, p. A18.

[53] http://www.salisbury.edu/sustain.

[54] Climate Action Plan – Progress Report: http://rs.acupcc.org/progress/282/

Moretti, E. *The New Geography of Jobs*. New York: Houghton Mifflin Harcourt Publishing Company. 2012.

Murray, T.J. and K. Hudson. *Virginia Shellfish Aquaculture Situation and Outlook Report: Results of 2011 Virginia Shellfish Aquaculture Crop Reporting Survey*. Virginia Sea Grant Marine Extension Program, Virginia Institute of Marine Science, May 2012.

Orth, R.J. and K.J. McGlathery, "Eelgrass Recovery in the Coastal Bays of the Virginia Coast Reserve, USA," *Marine Ecology Progress Series*, Vol. 448, 2012, p. 173-176.

Petrocci, C. "Heritage Tourism Workshop Draws Local Businesses," *The Crest*, Virginia Institute of Marine Science, Fall 2007, p. 5.

Program Brochure, Anheuser-Busch Coastal Research Center of the University of Virginia. University of Virginia, undated.

Pyke, C. R., *et al*. Climate Change and the Chesapeake Bay: State-of-the-Science Review and Recommendations. A Report from the Chesapeake Bay Program Science and Technical Advisory Committee (STAC), Annapolis, MD, 2008.

Salisbury University Climate Action Plan 2010. Salisbury University, January 15, 2010.

Sutphin, M. "21st-Century Extension." *Virginia Tech Magazine*. Fall 2011, p. 24-28.

Swallow, S.K., *et al*. "Ecosystem Services Beyond Valuation, Regulation, and Philanthropy: Integrating Consumer Values into the Economy," *Choices*, Vol. 23, 2008, p. 47.

The Princeton Review's Guide to 322 Green Colleges. Published by the Princeton Review in partnership with the U.S. Green Building Council, 2012 Edition.

Thomas, W.G., *et al*. "The Countryside Transformed: The Eastern Shore of Virginia, the Pennsylvania Railroad, and the Creation of a Modern Landscape," *Southern Spaces*, Emory University Libraries, July 31, 2007. http://www.southernspaces.org/2007/countryside-transformed-eastern-shore-virginia-pennsylvania-railroad-and-creation-modern-landsc

Bio

Sally Rood has managed and advocated for membership groups involved in science policy and technology transfer – including a university network, federal laboratory network, and industry innovation advisory committee – and engaged stakeholders at the intersection of science, technology, and economic development. She has worked regionally, internationally, and across a range of agencies on government-university-industry issues. Her academic background includes a PhD in Public Affairs, MBA in Information Technology, and masters in Science, Technology and Public Policy.

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Editors' Comments

Welcome to the Winter issue of the *Journal*! Physics and astronomy are the related themes of this issue, but before we get to that … in honor of the season, we've included some "snowflakes" for your viewing pleasure, as featured in **Al Teich's "Kaleidoscope Technology: The Intersection of Science and Art**."

We begin our astronomy/physics theme with **Sethanne Howard's** paper on the classification of astronomical objects and more specifically on how Pluto recently got voted out of the planets. **"Why Pluto is Not a Planet Anymore or How Astronomical Objects Get Named"** gets added to the long list of "good reads" by our Associate Editor who has been prolific in this *Journal* and others, writing such classics as "Black Holes Can Dance" (one of the *Journal's* most popular articles, as measured by the number of downloads from the WAS website), "The Dark Side of Astronomy," and "Creating Structure in Disk Galaxies."

Tom Kerwick's article, **"Colonizing Jupiter's Moons: An Assessment of Our Options and Alternatives"** discusses the possibilities of colonizing certain of Jupiter's moons to use them as bases for human scientific exploration in outer space. You'll learn that this is an exciting concept, as expanded from a November 23, 2012 blog entry entitled "Standing on the Shoulders of Giants: A Galilean Base" at the Lifeboat Foundation's web site, www.Lifeboat.com.

Bill Cornette's article reports on another concept related to physics and space. It's the continual development of a DoD computer application that predicts our radiative environment using mathematical algorithms modeling the physics of environmental regions – including the lower and upper atmosphere, space, terrain, and oceans – using first-principles physics models and large environmental databases constructed from satellite data and other sources. Involved team members at Computational Physics, Inc. (CPI) report that it is both satisfying and fulfilling to see the congruence of technical ideas developed over several decades culminate in CPI making this technology available to the public. Thus, this article is timely: As of January 2013, CPI has launched an entirely new initiative to offer comprehensive services based on this DoD-developed technology. Incidentally, if you're ever wondering what it would be like to work in a scientific firm such as CPI headquartered in the Washington DC area … for a first-hand account, check out "Day in the Life" under the Employment link at their website, www.CPI.com.[i]

Next we have **Albert Gluckman's** theoretical paper on the Special Theory of Relativity. The purpose of his article is to fill in some of the steps missing in Albert Einstein's 1905 paper where Einstein derives and defines the Special Theory of Relativity – equations that Einstein left to the reader at the time. So this paper is of interest for both the history of relativity and the student of relativity. If you take a look at Einstein's original paper, you'll see that Gluckman does fill in the missing steps using Einstein's actual notations which are not commonly used now. The paper gives two versions of the missing steps, one using the chain rule and another using the Taylor expansion. Long-time members of the Academy may recall that Albert Gluckman is a former Associate Editor of this *Journal* from the 1980s. During a conversation in the preparation of this paper for publication, Gluckman reminded us of a remarkable fact about our *Journal of the Washington Academy of Sciences*: During World War II, it was the only technical journal that published continuously during the war.

Those who are particularly fascinated by the articles of this issue will be interested to know that the Washington Academy of Sciences published a monograph on the first hundred years of astronomy in the *Journal of the Washington Academy of Sciences*. It contains eleven papers from 1905 to 2011, several by well-known astronomers and physicists. Entitled ***A Century of Astronomy in the Journal of the Washington Academy of Sciences***, the monograph is available from Amazon.com. As with the Gluckman article introduced above, we recommend it for its historical importance.

By the way, we welcome book reviews that are submitted to our *Journal* – or perhaps a review of the Academy's astronomy monograph!

Sally A. Rood, PhD, Editor

Sethanne Howard, PhD, Associate Editor

Journal of the Washington Academy of Sciences

[i] http://www.CPI.com

Kaleidoscope Technology: The Intersection of Science and Art

Al Teich
George Washington University

THE TWO IMAGES presented here are black and white digital photographs taken through a kaleidoscope. Invented by Sir David Brewster, a Scotsman, nearly 200 years ago, the kaleidoscope achieved instant popularity in the parlors of 19th century Europe. Hundreds of thousands were sold before the fad died out.

Figure 1. Northern Lights © Al Teich, 2006

During the past 30 years, kaleidoscopes have been enjoying a renaissance. They have become an important new mode of expression at the intersection of science and art, and have taken on an enormous range of forms and styles. Some of the more elaborate ones can sell for thousands of dollars.

I have a small collection of kaleidoscopes and began taking photographs through them about ten years ago. The one with which I

created these two photographs (Figures 1 and 2) is my favorite by far. It is different from traditional kaleidoscopes in several respects. The objects that make up its patterns are mainly black and white beads floating in oil inside a 1.5 cm thick Lucite puck. The puck is illuminated from the side rather than its back, so that the viewer is looking at, rather than through, the objects. And this kaleidoscope displays seven-fold symmetry—an unusual and interesting form requiring an extremely precise alignment of mirrors. While these images may look like snowflakes, their seven-fold symmetry makes it clear that they are not.

Figure 2. Impossible Snowflake © Al Teich, 2005

Photographing these ephemeral images gives me a means to capture and share them with others. I use a compact digital camera with a small lens and align it with the eyepiece of the 'scope. In principle, this is relatively simple, but in practice the alignment of camera and kaleidoscope, as well as the focusing, lighting, and digital processing require painstaking effort and have taken me considerable time to perfect. More kaleidoscope photographs can be found at http://www.kaleidoscopix.com/.

Why Pluto Is Not a Planet Anymore or How Astronomical Objects Get Named

Sethanne Howard
USNO retired

Abstract

Everywhere I go people ask me why Pluto was kicked out of the Solar System. Poor Pluto, 76 years a planet and then summarily dismissed. The answer is not too complicated. It starts with the question how are astronomical objects named or classified; asks who is responsible for this; and ends with international treaties. Ultimately we learn that it makes sense to demote Pluto.

Catalogs and Names

WHO IS RESPONSIBLE for naming and classifying astronomical objects? The answer varies slightly with the object, and history plays an important part.

Let us start with the stars. Most of the bright stars visible to the naked eye were named centuries ago. They generally have kept their old-fashioned names. Betelgeuse is just such an example. It is the eighth brightest star in the northern sky. The star's name is thought to be derived from the Arabic يد الجوزاء *Yad al-Jauzā'* meaning "*the Hand of al-Jauzā*", *i.e.*, Orion, with mistransliteration into Medieval Latin leading to the first character *y* being misread as a *b*. Betelgeuse is its historical name. The star is also known by its Bayer designation – ∝ Orionis. A Bayer[i] designation is a stellar designation in which a specific star is identified by a Greek letter followed by the genitive form of its parent constellation's Latin name. The original list of Bayer designations contained 1,564 stars. The Bayer designation typically assigns the letter alpha to the brightest star in the constellation and moves through the Greek alphabet, with each letter representing the next fainter star. However, there are only 24 letters in the Greek alphabet, so when a constellation has more than 24 stars, the list continues using lower case Latin letters and then upper case Latin letters where the convention stops at the letter Q. So Betelgeuse is the brightest star in the constellation Orion.

Since most constellations have many thousands of stars this type of designation quickly loses its value. Astronomers need a better way to identify stars. What worked for the pre-telescope days does not work now.

We need a system that can handle millions of stars. The answer is a catalog (a listing) that uses numbers instead of letters or names.

A star can appear in any number of catalogs that uniquely identify it. In most stellar catalogs a star is named (numbered) by its position across the sky, generally right ascension.[ii] For example, The Bright Star Catalog (BSC) numbers 9110 stars (down to 6.5 magnitude[iii]) in order from west to east for the year 1950. Each entry gives the identifying number and then the coordinates. Figure 1 shows a map of the sky according to the Bright Star Catalog. The bright star Vega (∝ Lyrae) is BSC 7001 in that catalog. There are several catalogs in active use by astronomers. Two important ones are the Hipparcos Catalogue (HIC) and Hubble Space Telescope Guide Star Catalogue. The HIC lists over 100,000 stars. The star Vega is HIC 91262 in that catalogue. The HST Guide Star Catalog lists 19 million unique stars between 6th and 16th magnitude. Vega is brighter than 6th magnitude so it is omitted from this particular catalog.[iv] Such numbering sequences, although boring to read, make it easy to find a star again and again.

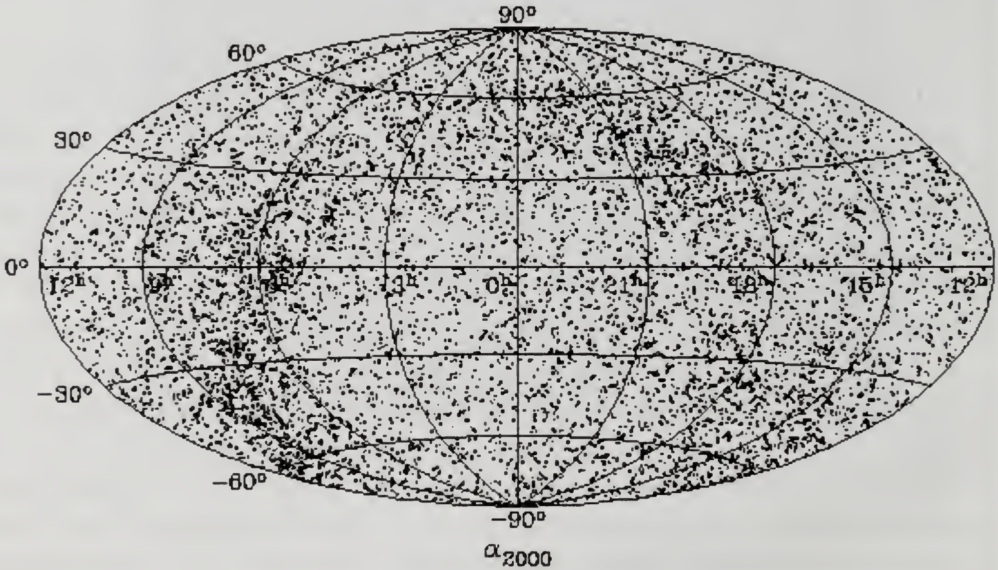

Figure 1. Stars in the Bright Star Catalog distributed by right ascension left to right and declination top to bottom.

There are many specialized stellar catalogs each useful for its class of stars. But there are other celestial objects that need identification. Galaxies have their own set of catalogs. And then there are the Solar System objects: planets, comets, and minor planets.

Once we have these catalogs, who or what makes them official? Anyone can number the stars, but it is the International Astronomical Union (IAU) that authorizes that number. The IAU is the internationally recognized authority (by treaty) for naming celestial bodies and surface features on them. Names are never sold, but assigned according to internationally accepted rules. Thus, like many wonderful things in human life, the beauty of the night sky is not for sale, but is free for all to enjoy.

The International Astronomical Union

Founded in 1919, the IAU's mission is to promote and safeguard the science of astronomy in all its aspects through international cooperation. Its individual members – structured in Divisions, Commissions, Working Groups, and Program Groups – are professional astronomers, at the Ph.D. level and beyond, and active in professional research and education in astronomy. In addition, the IAU collaborates with various organizations worldwide. The IAU has 10,894 Individual Members in 93 countries worldwide. The United States has signed the treaty related to the IAU; the appropriate reference in the US Code is Title 22 United States Code Section 274.

The IAU has been the arbiter of planetary and satellite nomenclature since its inception in 1919. At its inaugural meeting in 1922 in Rome, the IAU standardized the constellation names and abbreviations. More recently, IAU Committees or Working Groups have certified the names (numbers) of even more astronomical objects and features.

So we started with the historical naming of stars and have arrived at the treaty authorizing the naming and classification of all celestial objects. The IAU holds a general meeting every three years to process and vote on Resolutions. The last general meeting was held in Beijing in 2012. In between the general meetings are IAU special purpose symposia; however, Resolutions are processed only at the general meeting.

Our Solar System and its Minor Planets

In pre-telescope days, humans knew of six so-called 'planets': Mercury, Venus, Moon, Mars, Jupiter, and Saturn. It is seven, if one counts the Sun in this group. Hence, we have our historical seven day week with the responsibility for each day assigned to one of these seven objects. Today, of course, we know the Sun and Moon are not planets.

Once we had telescopes we learned of Uranus, Neptune, Pluto, and several minor planets. Textbooks could now identify nine planets in the Solar System.

The previous paragraph mentions the term *minor planet*. What defines a minor planet? The IAU has rules and definitions for this too. A minor planet is an astronomical object in direct orbit around the Sun that is neither a dominant planet nor originally classified as a comet. The term minor planet has been used since the 19th century to describe these objects. Historically, the terms *asteroid*, *minor planet*, and *planetoid* have been more or less synonymous. The dominant planets are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. Pluto I will discuss a bit later.

The first minor planet discovered was Ceres in 1801 (although from the time of its discovery until 1851 it was considered to be a planet). To date the orbits of more than 570,000 objects have been archived at the Minor Planet Center.[v] In the early days of discovery most minor planets were found to orbit between Mars and Jupiter. These were the asteroids and the Trojans (asteroids sharing Jupiter's orbit and gravitationally locked to it).

The issue became complicated by the modern discovery of numerous minor planets beyond the orbit of Jupiter and especially Neptune that are not universally considered asteroids. Therefore, minor planets can be dwarf planets, asteroids, Trojans, centaurs (bodies in the outer Solar System between Jupiter and Neptune), Kuiper belt objects (objects inside an apparent population drop-off approximately 55 astronomical units[vi] from the Sun), and other trans-Neptunian objects.

Not only are there a lot of them, but also some are quite large (like Eris), approaching Pluto in size and mass.

At its 2006 meeting, the IAU reclassified minor planets and comets into *dwarf planets* and *small Solar System bodies*. Objects are called "dwarf planets" if their self-gravity is sufficient to achieve hydrostatic equilibrium, that is, an ellipsoidal shape, with all other minor planets and comets called "small Solar System bodies." However, for purposes of numbering and naming, the traditional distinction between minor planet and comet is still followed.

The discoverer of a comet or minor planet has the privilege of suggesting a name to a special Committee of the IAU that judges its suitability. Contrary to some media reports, it is not possible to buy a

minor planet. If you have a name you would like to apply to a minor planet, the best advice is "Go out and discover one!"

As the number of asteroids began to run into the hundreds, and eventually the thousands, discoverers occasionally gave them increasingly frivolous names. The first hints of this were 482 Petrina and 483 Seppina, named after the discoverer's pet dogs. However, there was little controversy about this until 1971, upon the naming of 2309 Mr. Spock (the name of the discoverer's cat). Although the IAU subsequently banned pet names as sources, eccentric asteroid names are still being proposed and accepted, such as 4321 Zero, 6042 Cheshirecat, 9007 JamesBond, 13579 Allodd and 24680 Alleven, and 26858 Misterrogers. A well-established rule is that, unlike comets, minor planets may not be named after their discoverer(s).

Pluto

And then there is Pluto. Clyde Tombaugh discovered Pluto in 1930 at Lowell Observatory[vii] in Flagstaff, Arizona. Figure 2 shows the discovery photographic plates for Pluto. This became an international sensation – a new planet in the Solar System.

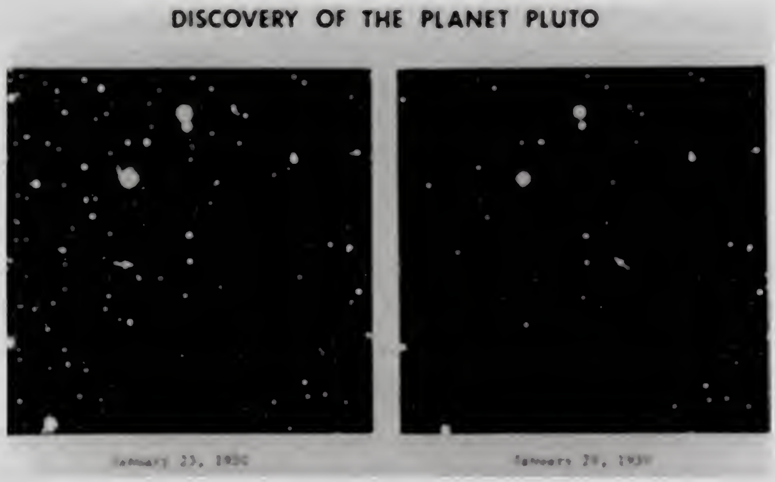

Figure 2. Two photographic plates showing the discovery of Pluto (marked with the small arrow). It moves with respect to the background stars between the two photographs.

The discovery made headlines across the globe. The Lowell Observatory, which had the right to name the new object, received more than 1,000 suggestions from all over the world, ranging from Atlas to Zymal. Constance Lowell proposed *Zeus*, then *Percival*, and finally *Constance*. These suggestions were disregarded.

The name *Pluto* was proposed by Venetia Burney (1918–2009), an eleven-year-old schoolgirl in Oxford, England. She was interested in classical mythology as well as astronomy, and considered the name, a name for the god of the underworld, appropriate for such a presumably dark and cold world. She suggested it in a conversation with her grandfather Falconer Madan, a former librarian at the University of Oxford's Bodleian Library. Madan passed the name to Professor Herbert Hall Turner, who then cabled it to colleagues in the United States.

The object was officially named on March 24, 1930. Each member of the Lowell Observatory was allowed to vote on a short-list of three: *Minerva* (which was already the name for an asteroid), *Cronus* (which lost supporters through being proposed by the colorful but unpopular astronomer Thomas Jefferson Jackson See[viii]), and *Pluto*. Pluto received every vote. The name was announced on May 1, 1930. Upon the announcement, Madan gave Venetia five pounds (£5) as a reward.

The name was soon embraced by the wider culture. In 1930, Walt Disney introduced a canine companion, named Pluto, for Mickey Mouse apparently in the object's honor, although this is not confirmed. In 1941, Glenn T. Seaborg named the newly created element plutonium after Pluto, in keeping with the tradition of naming elements after newly discovered planets, following uranium, which was named after Uranus, and neptunium, which was named after Neptune.

Now firmly in place as a Solar System planet, Pluto needed to be visited. NASA decided to send a space probe to it. In August 1992, the Jet Propulsion Laboratory scientist Robert Staehle called Tombaugh, requesting permission to visit his planet. "I told him he was welcome to it," Tombaugh later remembered, "though he's got to go one long, cold trip." The call eventually led to the launch in 2006 of the New Horizons space probe to Pluto. It will fly past Pluto in 2015.

Tombaugh died on January 17, 1997 in Las Cruces, New Mexico, at the age of 90. Approximately one ounce of his ashes is being carried on the New Horizons space probe. The container includes the inscription: "Interred herein are remains of American Clyde W. Tombaugh, discoverer of Pluto and the Solar System's 'third zone'." I was extremely privileged to meet him at his 85th birthday party.

Following its discovery until 2006, Pluto was classified as a planet. Pluto has five known moons, the largest being Charon discovered in 1978, along with Nix and Hydra, discovered in 2005, and the provisionally

named S/2011 (134340) 1, discovered in 2011. Another discovery was announced July 11, 2012, provisionally designated S/2012 (134340) 1, bringing the total number of identified satellites orbiting Pluto to five. Pluto and Charon are sometimes described as a binary system because the barycenter of their orbits does not lie within either body. However, the IAU has yet to formalize a definition for binary dwarf planets and, as such, Charon is officially classified as a moon of Pluto.

Too Many Plutos?

Evidence began to accumulate that Pluto was not unique. In the late 1970s, following the discovery of minor planet 2060 Chiron in the outer Solar System and the recognition of Pluto's relatively low mass, its status as a dominant planet began to be questioned. In the late 20th and early 21st centuries, many objects similar to Pluto were discovered in the outer Solar System, notably the object Eris in 2005, which is 27% more massive than Pluto. Eris has one moon. Subsequent observations show that it is currently uncertain which is the larger, Eris or Pluto.

The time was ripe, therefore, for a new classification system. The IAU had a choice: keep Pluto as a planet, and include all similar objects as planets too; or, demote Pluto. They chose the second option.

The IAU had never officially defined a "planet;" there had been no need until there were too many Plutos. It rectified this at its 2006 general meeting. On August 24, 2006, at the XXVIth General Meeting, the IAU voted to define what it means to be a "planet" within the Solar System (see Resolution B5 and Resolution B6 in the appendix). This definition excluded Pluto as a planet and added it as a member of the new category "dwarf planet" along with Eris and Ceres. After the reclassification, Pluto was added to the list of minor planets and given the number 134340.

A number of astronomers hold that Pluto should continue to be classified as a planet (especially since it has a cluster of moons), and that other dwarf planets should be added to the roster of planets along with Pluto.

A Detailed Description of How Minor Planets are Named

The assignment of a particular name to a particular minor planet is the end of a long process that can take many decades. It begins with the discovery of a minor planet that cannot be identified with any already-known object. Such minor planets are given a provisional designation. The provisional designations are based on the date of discovery and are

assigned by the Minor Planet Center according to a well-defined formula that involves the year of discovery, two letters and, if need be, further digits (for example, 1989 AC, or 2002 LM60).

When the orbit of a minor planet becomes well enough determined that the position can be reliably predicted far into the future (typically this means after the minor planet has been observed at four or more oppositions[ix]), the minor planet receives a permanent designation. This is a number issued sequentially by the Minor Planet Center, for example (433), (4179) or (50000).

When a minor planet receives a permanent number, the discoverer of the minor planet is invited to suggest a name for it. The discoverer has this privilege for a period of ten years following the numbering of the object.

The discoverer writes a short citation explaining the reasons for assigning the name according to the guidelines of the IAU. Proposed names should be:

- 16 characters or less in length
- preferably one word
- pronounceable (in some language)
- non-offensive
- not too similar to an existing name of a minor planet or natural planetary satellite.

The names of individuals or events principally known for political or military activities are unsuitable until 100 years after the death of the individual or the occurrence of the event.

All proposed names are judged by the fifteen-person Working Group for Small Body Nomenclature (WGSBN) of the IAU, comprised of professional astronomers with research interests connected with minor planets and/or comets from around the world. As an example, the asteroid 29085 Sethanne (1979 SD) has the citation:

> "Sethanne Howard (b. 1944) is an American astronomer who has held positions with U.S. national observatories, NASA, the National Science Foundation, and the U.S. Navy; Chief of the U.S. Nautical Almanac Office, 2000-2003. Her research specialty is galactic dynamics. She has also been active in science education, especially concentrating on the history of women in science."

The asteroid was discovered by Brian Marsden who graciously named it for his colleague.

Comets follow a similar naming procedure, except the name can be that of the discoverer. Usually two or three new comets are discovered each year. Most are too faint to be of general interest.

Naming Planetary Features

That IAU also has responsibility for naming planetary surface features (*e.g.*, craters). The IAU has a system of uniquely identifying features on the surface of planets or natural satellites so that the features can be easily located, described, and discussed. Names must follow various rules and conventions established and amended through the years by the IAU. These include:

1. The first consideration should be to make the name simple, clear, and unambiguous.
2. Features whose longest dimension is less than 100 meters are not assigned official names unless they have exceptional scientific interest.
3. The number of names chosen for each body should be kept to a minimum, and their placement governed by the requirements of the scientific community.
4. Duplication of the same name on two or more bodies is to be avoided.
5. Individual names chosen for each body should be expressed in the language of origin. Transliteration for various alphabets should be given, but there will be no translation from one language to another.
6. Where possible, the themes established in early Solar System nomenclature should be used and expanded on.
7. Solar System nomenclature should be international in its choice of names. Recommendations submitted to the IAU national committees will be considered, but final selection of the names is the responsibility of the IAU. The WGPSN[x] strongly supports equitable selection of names from ethnic groups/countries on each map; however, a higher percentage of names from the country planning a landing is allowed on landing site maps.

8. No names having political, military, or religious significance may be used, except for names of political figures prior to the 19th century and gods and goddesses of ancient religions.

9. Commemoration of persons on planetary bodies should be reserved for persons of high and enduring international standing. Persons being so honored must have been deceased for at least three years.

10. When more than one spelling of a name is extant, the spelling preferred by the person, or used in an authoritative reference, should be used. Diacritical marks are a necessary part of a name and will be used.

11. Ring and ring-gap nomenclature and names for newly discovered satellites are developed in joint deliberation between WGPSN and IAU Commission 20. Names will not be assigned to satellites until their orbital elements are reasonably well known or definite features have been identified on them.

For example, craters on Mercury are named for famous deceased artists, musicians, painters, and authors. Features on Venus are named for ancient goddesses or deceased famous women. Small craters on Mars are named for villages of the world with a population of less than 100,000.

Conclusion

It is clear that Pluto was a victim of the discoveries of a multitude of Solar System objects quite similar to Pluto. Pluto is no longer unique. So many such objects have been found that it became necessary to redefine what makes a planet. The IAU took action, demoted Pluto, and set it amongst the objects similar to it in size. It does mean that textbooks must now define a Solar System planet to be one of eight planets instead of nine. This is sad for those of us old enough to remember learning our nine planet Solar System, but it settles the issue for the future.

Appendix

The IAU approved the following two resolutions at its XXVI[th] General Meeting, August 24, 2006:

Resolution B5

Contemporary observations are changing our understanding of planetary systems, and it is important that our nomenclature for objects reflect our current understanding. This applies, in particular, to the designation "planets". The word "planet" originally described "wanderers" that were known only as moving lights in the sky. Recent discoveries led us to create a new definition, which we can make using currently available scientific information.

The IAU therefore resolves that planets and other bodies, except satellites, in our Solar System be defined into three distinct categories in the following way:

(1) A planet[1] is a celestial body that
- (a) is in orbit around the Sun,
- (b) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape, and
- (c) has cleared the neighbourhood around its orbit.

(2) A "dwarf planet" is a celestial body that
- (a) is in orbit around the Sun,
- (b) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape[2],
- (c) has not cleared the neighbourhood around its orbit, and
- (d) is not a satellite.

(3) All other objects[3], except satellites, orbiting the Sun shall be referred to collectively as "Small Solar System Bodies".

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[1] The eight planets are: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune.

[2] An IAU process will be established to assign borderline objects to the dwarf planet or to another category.

[3] These currently include most of the Solar System asteroids, most Trans-Neptunian Objects (TNOs), comets, and other small bodies.

Resolution B6

The IAU further resolves:

Pluto is a "dwarf planet" by the above definition and is recognized as the prototype of a new category of Trans-Neptunian Objects[1].

[1] An IAU process will be established to select a name for this category.

[i] The17th century German astronomer Johann Bayer.

[ii] Angle to the east of the Vernal equinox.

[iii] A magnitude is a measure of brightness.

[iv] HST cannot look at bright stars.

[v] Under the auspices of the IAU, the Minor Planet Center is the official organization in charge of collecting observational data for minor planets (asteroids) and comets, calculating their orbits and publishing this information.

[vi] The distance from the Earth to the Sun.

[vii] Lowell Observatory was established in 1894.

[viii] Thomas Jefferson Jackson (T. J. J.) See (February 19, 1866 – July 4, 1962) was an American astronomer who was infamous for a career dogged by plagiarism, being fired from two observatories, being 'exiled' to an isolated outpost, and his vitriolic attacks on relativity.

[ix] *i.e.*, the orbit is well determined.

[x] Working Group on Planetary Surface Nomenclature.

Bio

Sethanne Howard is an astronomer who has held positions with U.S National Observatories, NASA, the National Science Foundation, and the U.S. Navy. She was Chief of the U.S. Nautical Almanac Office, 2000-2003. Her research specialty is galactic dynamics. She has also been active in science education, especially concentrating on the history of women in science.

Colonizing Jupiter's Moons: An Assessment of Our Options and Alternatives

Thomas B. Kerwick
The Lifeboat Foundation / CEVA, Inc.

Abstract

At the Lifeboat Foundation, we discuss the sustainability of Earth's resources and ecosystems, existential risks to life on Earth, and the safeguards to human existence that could be achieved by eventually branching out and colonizing space. Overviewing current possibilities in manned space exploration and eventual colonization within our Solar System, instinct draws us to consider a permanent base on either the Moon or Mars. Here, I consider what could be a rewarding alternative — outward to the first of the gas giants — and the Galilean moons of Jupiter.

The Galilean Giants

ALTHOUGH THE MOON AND MARS provide possible permanent bases for humans, there are alternatives to them. The polar regions of Mercury, for example, have been suggested because of the suspected presence of water-ice [1] and an abundance of natural resources. Transforming Venus could also be a long term prospect if its runaway greenhouse effect could be permanently reversed. There is a further choice: the Galilean moons.

The Galilean moons are the four large moons of Jupiter which were discovered by Galileo in 1610, their names derived from the lovers of Zeus – Io, Europa, Ganymede, and Callisto. Although Jupiter has 67 confirmed moons [2], the four Galilean moons, with radii larger than any of the dwarf planets in our Solar System, contain the vast majority of the mass in orbit around Jupiter. Indeed the next largest of the Jovian satellites, Himalia and Amalthea, are both less than a mere 200 km in diameter. The Galilean moons, with diameters 3,600 km (Io), 3,120 km (Europa), 5,260 km (Ganymede) and 4,820 km (Callisto) are among the most massive objects in the Solar System after the Sun and the eight planets.

We already know a great deal about the Galilean moons which have been visited by several unmanned spacecraft from the arrival of Pioneer 10 in 1973 to the most recent visit of the New Horizons probe in 2007 en route to Pluto. The Galileo orbiter is the only spacecraft that orbited Jupiter – which it did for over seven years until it was eventually

destroyed during a controlled impact with Jupiter in 2003 [3]. Other spacecraft to visit the Jovian system include: Pioneer 11 (1974), Voyager 1 and Voyager 2 (1979), Ulysses (1992), and Cassini (2000). It is from the success of these unmanned spacecraft that we owe most of our knowledge of the Galilean moons and the Jovian system. This includes not just dramatic images of these moons, but an insight into the mass, topography, volcanism and tectonic processes. The images and insights provide evidence of liquid salt water sub-surfaces and atmospheres, and information on the orbital precision of these moons and the magnetic field and radiation belts through which they orbit in the Jovian system.

Reasons to be Enthusiastic

From a scientific point of view and for the advancement of space exploration, we may appreciate reasons to be enthusiastic about setting up a base in the Jovian system. It provides the nearest possible location to Earth where a base could be established to explore the dynamics and weather systems of large gaseous/liquid planets in detail, and study how such planets impact and interact with their satellites. With large gas planets believed to be quite common in our Universe (almost all known exo-planets are of this form [4]) the invitation seems obvious – to explore how such planets affect their moons in order to understand the suitability of such locations for an off-Earth industrial/scientific base toward long-term aspirations for space exploration/colonization. It is worth noting that only two other moons in our outer Solar System are of requisite size to have a gravitational field similar to or greater than that of our Moon — namely Saturn's Titan and Neptune's Triton. Since a significant gravitational field is one of the fundamental essentials for the physical well-being of would-be explorers, the Galilean moons naturally demand our attention for review.

With four such large moons to study in the one region of our Solar System, along with their parent gas giant, we have a uniquely diverse region from Io, the most geologically active body in our Solar System to the water-rich icy moon Europa, often credited as the most likely place in our Solar System where we might find traces of alien life. If we were to consider where a scientific base would maximize its return, the Galilean moons are inviting.

The Great Deterrent: Jovian Radiation

The first difficulty to consider in setting up a base in this region is the intense radiation from Jupiter, which is far stronger than that from the Earth's Van Allen radiation belts. This radiation is formed from charged particles trapped in Jupiter's magnetosphere, a zone one million times the volume of Earth's magnetosphere. The inner magnetosphere, rotating very rapidly with the planet, is a constant presence and a constant deterrent. At greater distances, more than 20 times the radius of Jupiter, the magnetic field becomes blunted by the solar wind on the sunward side, and extended on the leeward side. So the size of the outer magnetosphere varies depending on the intensity of the solar wind. However, in considering setting up a base in this region we would have to consider the worst case scenario of intolerable radiation levels, and not just typical reach and intensities. Proper shielding normally protects living organisms and electronic instrumentation in space voyages. However, as the radiation from Jupiter is whipped up from magnetic fields far stronger than those on Earth (the strongest fields in the Solar System except for sun spots), shielding becomes a much greater challenge. It has been suggested that such radiation would be the greatest threat to any craft closing within 300,000 km of the planet [5], although radiation levels would still be of great concern to us at distances far greater than this.

As illustrated in Figure 1, the magnetic field of Jupiter stretches far beyond the orbit of even the outermost of the Galilean moons, elongated by the solar wind in the anti-solar direction. The field is a complex structure comprising many components including bow shock, magnetosheath, magnetopause, magnetotail, magnetodisk and – most significantly for the purposes considered here – the currents induced as the ionosphere moves relative to Jupiter's dipole magnetic field under the rotation of the planet. A resulting Lorenz force to these currents drives negatively charged electrons to the poles and positively charged ions towards the equator. Due to the presence of highly conductive plasma in Jupiter's magnetosphere, the electrical circuit is considered closed through that force. Estimated at around 60-140 million amperes [6], this current flows along the magnetic field lines from the ionosphere (the direct current) to the equatorial plasma sheet before flowing radially away from the planet within the radial current sheet (the radial current), before finally returning to the ionosphere from the outer reaches of the magnetosphere along the field lines to the poles (the return current).

The Galilean moons orbit through this equatorial plain of Jupiter and receive high levels of radiation – with Io estimated at receiving approximately 3,600 rem/day, Europa 540 rem/day, and Ganymede 8 rem/day. Furthest out, Callisto receives a less problematic 0.01 rem/day.

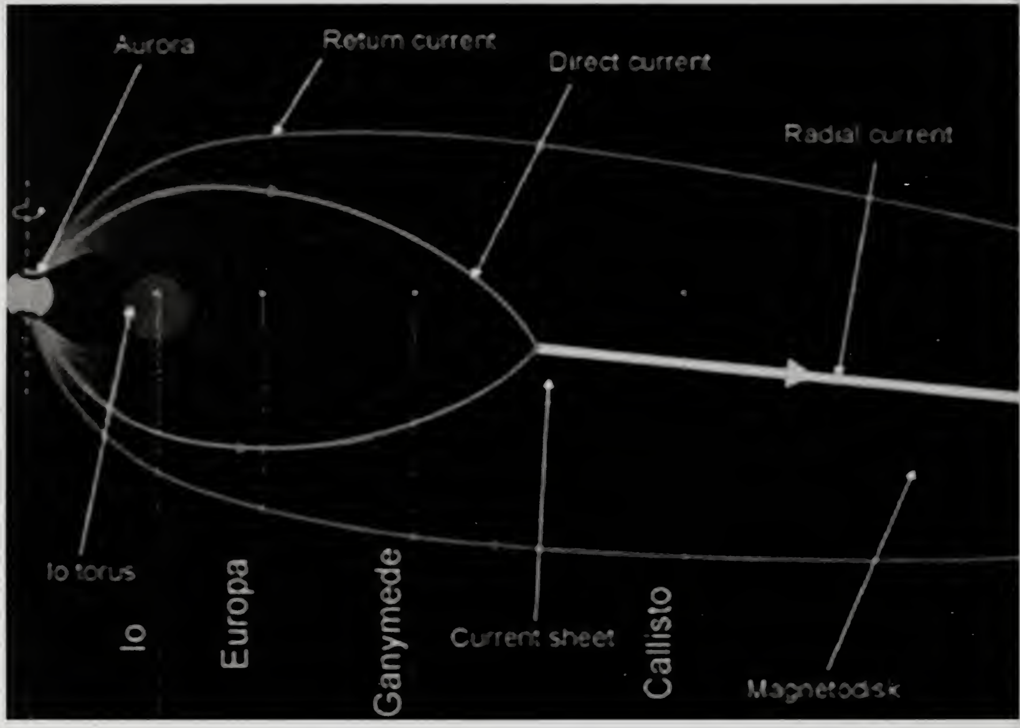

Figure 1: The magnetic field of Jupiter and co-rotation enforcing currents.

The large magnetosphere also has an important function in the region in that it protects the four largest moons of Jupiter – which all orbit within the magnetosphere – from the solar wind. Outside the Jovian radiation belts, the magnetosphere is an important blanket over the region. This is in stark contrast to a hypothetical base on either the Moon or Mars where there is no such blanket. So we can consider the magnetosphere here to provide opportunity and not just deter.

However, with radiation levels of 500 rem or greater considered a fatal dose, and as little as 75 rem over a period of a few days enough to cause radiation poisoning [13], there is little room to argue that Jovian radiation is a significant obstacle to astronauts visiting the region.

More Deterrents: Distance and Low Temperatures

At closest approach Jupiter and Earth are 630 million km apart, or 4.2 AU. This is an order of magnitude further than the closest approach of Mars to Earth, at 56 million km. Such distance makes a manned voyage impractical without significant advancement on spacecraft design, as we frequently find estimates of round trips to Mars proposed in the order of two years.

To meet the challenge of such great distances, one propulsion of choice at NASA in recent years has become ion propulsion, where the High Power Electric Propulsion (HiPEP) project has demonstrated exhaust velocities in excess of 90,000 meters/second (over 200,000 mph) [7]. Although the mission HiPEP was originally designed for the Jupiter Icy Moons Orbiter, that mission was cancelled in 2005. Nevertheless, the technology can be considered ground-tested and feasible.

An advanced ion propulsion drive could reduce a voyage to Jupiter significantly – although we should note that HiPEP research looked at lighter unmanned spacecraft, and achieving such figures with heavier manned space craft could be considered fanciful. However, with continued investment in space aviation research, we will sooner or later be considering round trips to the Jovian moons with sub-year voyage estimates. So we should not exclude outright the feasibility of manned missions to the Jovian system due to the distances involved.

Temperature is another matter to consider. Objects travelling through space experience temperatures that are quite extreme compared to what the same objects would experience on Earth. The effective temperature of space is extremely cold – approximately 3K [8]. When astronauts perform spacewalks above Earth, the spacesuit can have a temperature difference of up to 275° F from one side to the other, with one side of the spacesuit facing towards the Sun and the other facing out to the cold of deep space. In the Jovian environment with the Sun far more distant, even temperatures on the Sun facing side are extremely cold, with temperatures rarely rising above 170K on any of the Galilean moons.

The mean temperature on Callisto is estimated at 135K with a variation of ±50K [9]. The temperatures of Ganymede [10] and Io (discounting the extreme temperatures near hot spots and volcanic plumes) [11] are estimated at 110K, again with a variation of ±50K or so. That of Europa (due to its higher albedo) is lower, at 100K [10], again with a similar variation. While variation in temperature is not a concern here, the

absolute temperature is of concern. For a manned mission to succeed, the spacesuits would require a durable thermal energy source to ensure sufficient comfort for astronauts. A significant design consideration of any base would require a reliable method of sustaining temperatures far higher than natural conditions.

An Overview of the Galilean Giants

Io

At a distance of 420,000 km, Io is the closest of the Galilean satellites to Jupiter – a proximity that results in making Io a highly active world. Tidal heating from friction generated within Io's interior under the gravitational influence of Jupiter and the other Galilean satellites leave the Ionian surface in a constant state of renewal with volcanic activity from more than 400 active volcanoes. Io is, in fact, considered the most geologically active object in the Solar System, and plumes rich in sulphur and sulphur dioxide regularly rise as high as 400 km above the surface.

We can disregard an extremely thin sulphur dioxide atmosphere as an inconvenience. However, a surface prone to explosive volcanism and extensive silicate lava flows, and exposed to high levels of Jovian radiation – estimated at 3,600 rem/day – far above dosages considered fatal for humans – make Io an unlikely satellite to visit. However, if the tidal heating on Io could be harnessed as a source of heat/energy (it has been estimated that the global total heat flow from Io is in the region of 1×10^{14} W [12]), this would provide a reliable energy source for a base in the region – if technical challenges such as providing sufficient radiation shielding could be overcome – either on one of the other Galilean giants or an orbiting space station.

It is also worth noting that, unlike most satellites, Io is composed of silicate rock with a molten iron or iron sulphide core, so this may provide mining opportunities. However, being hazardous as a region, we may have to rule out Io and any of its resources from practical considerations.

Europa

Europa is the smallest of the Galilean giants, with a radius of just over 1,500 km, but still one of the largest moons in the Solar System. It is just slightly smaller than Earth's Moon. With a possible sub-glacial water ocean [13] underneath its icy exterior, it has been suggested not just as a

target suited for eventual human colonization, but also as a possible host to alien life forms.

The abundance of water is significant not only as a source of drinking water, but it could also be broken down to provide breathable oxygen. However, the colonization of Europa poses many difficulties. At 670,000 km from Jupiter, Europa receives 540 rem of radiation per day from the Jovian radiation belts, and this would be considered a fatal dose (> 500 rem). Humans would not survive at or near the surface of Europa for long without significant radiation shielding. It is also extremely cold on Europa – even colder than on the other Galilean giants – due to its high albedo – reflecting off most of the light and heat that reaches its surface. Also, although Europa has a great abundance of water, it is lacking in accessible minerals and irons. With the water ocean under the ice surface thought to be up to 100 km thick, all materials required for construction would need to be mined and transported from other satellites in the Jovian region.

Even overcoming these difficulties, one of the first dilemmas of setting up a base on Europa would be to not contaminate any primitive life that may already have a foothold there. Studies have indicated that the action of solar radiation on the surface of Europa might produce oxygen, which could be pulled down into the subsurface ocean by upwelling from the interior. If this process occurs, Europa's subsurface ocean could have an oxygen content equal to or greater than that of the Earth's – possibly providing a home to complex life [14]. Often considered a strong candidate for extra-terrestrial microbial-type life, if such were found, it could render Europa off-limits for colonization on the grounds of ethics due to the possible contamination/destruction of a delicate ecosystem. Conversely, human colonists coming into contact with such microbes could find that their immune systems do not offer a natural defense to alien microbes which evolved to become more durable to the natural conditions on Europa.

Discounting this, and with sufficient radiation shielding, Europa offers an intriguing location for a research base – having an abundant supply of drinking water and oxygen by extraction.

Ganymede

Ganymede is not only the largest of the Galilean giants, but is also the largest and most massive moon in the Solar System – larger in diameter than the planet Mercury, albeit with just 45% of Mercury's mass.

This results in an escape velocity of 2.741 km/s, somewhat larger than that of Earth's Moon, which has an escape velocity of 2.38 km/s. Therefore, the long-term effects on astronauts are least severe here due to weakened gravity environments.

Considerably further out than both Io and Europa, at over 1,070,000 km from Jupiter, Ganymede is also exposed to far lower levels of Jovian radiation when compared to Io or Europa. An unshielded colonist would receive about 8 rem of radiation per day on Ganymede, compared to what would be considered fatal doses of 540 rem/day on Europa or 3,600 rem/day on Io.

However, exposure of approximately 75 rems over a period of a few days is enough to cause radiation poisoning [15]. Astronauts on Ganymede would still require a significant level of radiation shielding in order to operate here, although much of this low-latitude region is partially shielded by Ganymede's magnetic field.

In considering potential off-Earth bases in the Solar System, a shielded underground base on Ganymede may be a reasonable long-term objective. Ganymede is the only satellite in the Solar System to boast a magnetosphere. This is thought to be produced by convection in a liquid iron core [16], where temperatures are estimated to be 1500-1750K. This internal heat source can counter the extreme cold conditions of 70-150K on the surface in an underground facility. Beneath a composition of silicate rock and water-ice in roughly equal proportions near its surface, Ganymede is also considered likely to have a salt water ocean far below its surface [17] due to magnesium sulphate and sodium sulphate salts which showed up in results from the Galileo spacecraft, along with detected signs of carbon dioxide and organic compounds [18], trace amounts of oxygen, and ozone. Such a salt water ocean could be not only a source from which ample drinkable water could be distilled, but also a source from which oxygen could be extracted. Furthermore, evidence of trace amounts of carbon dioxide and organic compounds suggests an intriguing world to analyze with a view to developing terraforming processes.

Also, it should not be overlooked that Ganymede has abundant resources in silicates and irons suitable for mining and construction, unlike many other satellites where water-ice dominates.

While aspirations such as mining and construction of permanent bases may seem far-fetched in our current age, foresight should be

applied. This will ensure, where we attempt to initiate a foothold in such a remote region, that long-term prospects are considered, and that the region is the most suited to industrial progression. In this light, Ganymede weighs in with several advantages.

Callisto

The outermost of the Galilean giants, Callisto is almost 2,000,000 km from Jupiter, twice the distance of Ganymede from Jupiter, and hence the least affected by Jovian radiation. For this reason, Callisto was selected by NASA as the most suitable place to create a human base for future exploration of the Jupiter system when HOPE, Human Outer Planet Exploration, was presented. At that time, some of the objectives and requirements for such a pilot mission were explored [19].

Being darker, the surface of Callisto is warm relative to Europa and Ganymede (a darker surface reflects less light, and therefore retains more heat/energy), and it also benefits from a much thicker atmosphere [20]. The CO_2 component of Callisto's atmosphere was first detected by the Galileo mission's imaging spectrometer, NIMS, but recent modeling suggests an even more robust atmosphere. Interaction between a more substantial ionosphere and Jupiter's magnetosphere reduces electron impact, and the relatively thick atmosphere also protects the surface significantly from radiation flux. To put these figures in context, the surface pressure on Callisto is estimated at 7.5 pbar, while the estimated maximum surface temperature is 170K – still extreme conditions for any astronauts.

The escape velocity on Callisto is similar to that for Ganymede at 2.44 km/s. Therefore, again, the long-term effects on astronauts due to weakened gravity environments would not be as severe here as it would be on smaller worlds.

Callisto is a geologically inactive world, with no signatures of subsurface processes such as plate tectonics or volcanism. Not being subjected to tidal heating, Callisto has similarities with Ganymede in that it is also believed to have a subsurface ocean of liquid water. Hence, it would have an unlimited supply of drinking water and oxygen by extraction. Organic compounds have also been detected through spectroscopic measurements [20]. One proposition for Callisto may be the introduction of genetically-modified vegetation – robust to cold surface temperatures and capable of surviving in a weak CO_2 atmosphere, to grow here as renewable food sources.

As with Ganymede – and unlike Europa – Callisto has abundant accessible resources in silicates and irons that are suitable for mining and construction. A successfully established base here could be augmented over time into a more ambitious industrial base and colony if viable.

Vehicle and robot system concepts were explored toward achieving a successful first phase for the HOPE surface operation. The division of tasks between crew and robotics were analyzed for the exploration of all the Jovian satellites. It was concluded that a round trip of a crewed mission would require 2-5 years — albeit with significant advancement in propulsion technologies.

Perhaps the greatest challenge to establishing a base on Callisto relative to Ganymede, which is clearly the only other viable alternative in the region – involves questions of how to elevate the temperature of a base here to comfortable conditions in a self-sustainable process, and how to generate sufficient energy and electricity to meet the needs of such a base. Lacking an internal source of heat – and with little opportunity in the way of solar, tectonic, or other energy sources – presents an engineering trade-off with Ganymede's radiation shielding needs and complications.

Conclusions

While unmanned spacecraft have allowed us to learn a great deal about the Jovian system, a long term goal of human exploration to the region would allow us to learn a great deal more.

The Jovian system is a fascinatingly diverse region of our Solar System just awaiting mankind to explore it. In both Ganymede and Callisto, it has two bodies which could be considered to be viable options for a scientific base if specific engineering challenges can be overcome.

A study performed in recent years has suggested an initial manned round trip to the region could be achieved in 2-5 years, given sufficient advancement in propulsion technologies. It is doubtful anyone would argue that the diversity of the region is a far more appealing invitation to explore than alternatives such as Mars or the polar regions of Mercury. What we considered here is whether such a mission, leading to an eventual base, would be a viable option. In this light, we must conclude that there are options in the Jovian system that offer viable alternatives within our Solar System.

Acronyms and Abbreviations

AU	The Astronomical Unit 149,597,870,700 meters (the mean Earth-Sun distance).
Galileo NIMS	Near-Infrared Mapping Spectrometer, the Galileo mission's imaging spectrometer.
HiPEP	High Power Electric Propulsion (a NASA research project, c.2003-2004).
HOPE	Human Outer Planet Exploration (a NASA-led study on space exploration c.2003).
rem	Roentgen Equivalent Man, the US unit of measurement for a radiation dose.

References

[1] Ice on Mercury. – Williams, David R. National Space Science Data Centre, NASA. Retrieved 2013-02-03. http://nssdc.gsfc.nasa.gov/planetary/ice/ice_mercury.html

[2] The Giant Planet Satellite and Moon Page. Sheppard, Scott S. Department of Terrestrial Magnetism, Carnegie Institution. Retrieved 2013-02-03. http://www.dtm.ciw.edu/users/sheppard/satellites/

[3] Galileo Mission to Jupiter. NASA Jet Propulsion Laboratory. Retrieved 2013-02-03. http://www.jpl.nasa.gov/news/fact_sheets/galileo0309.pdf

[4] Habitability of Known Exoplanetary Systems Based on Measured Stellar Properties. Jones, Barrie W., Sleep, P. Nick, Underwood, David R. 2006. http://arxiv.org/ftp/astro-ph/papers/0603/0603200.pdf

[5] Jupiter Radiation Belts are Harsher than Expected. Media Relations Office, NASA Jet Propulsion Laboratory. March 28, 2001. http://www.jpl.nasa.gov/releases/2001/belts.html

[6] The Configuration of Jupiter's Magnetosphere. pp. 13-16. Khurana, Krishan K. *et al.* 2004. http://www.igpp.ucla.edu/people/mkivelson/Publications/279-Ch24.pdf

[7] Ion Propulsion Fact Sheet. NASA Glenn Research Center. FS-2004-11-021-GRC. Retrieved 2013-02-04. http://www.nasa.gov/centers/glenn/about/fs21grc.html

[8] Eddington's Temperature of Space. Wright, Edward L. UCLA Division of Astronomy and Astrophysics. 2006. Retrieved 2013-02-04. http://www.astro.ucla.edu/~wright/Eddington-T0.html

[9] Callisto – Thermal Characteristics. Moore, Jeffrey M. *et al.* Laboratory for Atmospheric and Space Physics, University of Colorado 2008. http://lasp.colorado.edu/~espoclass/homework/5830_2008_homework/Ch17.pdf

[10] Ice Chemistry on the Galilean Satellites. Delitsky, Mona L., Lane, Arthur L. Jet Propulsion Laboratory. California Institute of Technology. September 30, 1998. http://trs-new.jpl.nasa.gov/dspace/bitstream/2014/20675/1/98-1725.pdf

[11] The Lithosphere and Surface of Io. McEwen, Alfred S. *et al.* Laboratory for Atmospheric and Space Physics, University of Colorado. 2008 http://lasp.colorado.edu/~espoclass/homework/5830_2008_homework/Ch14.pdf

[12] Tidal Heating and Convection on Io. Moore, W. B. Journal of Geophysical Research. August 26, 2003. http://cips.berkeley.edu/events/rocky-planets-class09/Moore_heating_io.pdf

[13] "Thin ice opens lead for life on Europa." Chandler, D. L. New Scientist. October 2002. http://www.newscientist.com/article/dn2929-thin-ice-opens-lead-for-life-on-europa.html

[14] "Europa Capable of Supporting Life, Scientists Say." Atkinson, Nancy. Universe Today. October 2009. http://www.universetoday.com/42303/europa-capable-of-supporting-life-scientist-says/

[15] "Ganymede's magnetosphere: magnetometer overview." Kivelson, M. G. *et al.* Journal of Geophysical Research. August 30, 1998. http://www.igpp.ucla.edu/people/rwalker/Publications/98JE00227.pdf

[16] "The Permanent and Inductive Magnetic Moments of Ganymede" Kivelson, M. G. *et al.* 2002. http://www.igpp.ucla.edu/public/mkivelso/Publications/ICRUS1572507.pdf

[17] "Hydrated Salts on Ganymede's Surface: Evidence of an Ocean Below." McCord, Thomas B. *et al.* Science. May 25, 2001. http://www.sciencemag.org/content/292/5521/1523.abstract

[18] "Non-water-ice constituents in surface material of the icy Galilean satellites from the Galileo near-infrared mapping spectrometer investigation." McCord, T. B. *et al.* U.S. Geological Survey. 1998. http://pubs.er.usgs.gov/publication/70020288

[19] Human Outer Planet Exploration, HOPE, NASA Academy Presentation. 2003. Retrieved 2013-02-04. http://www.nasa-academy.org/soffen/travelgrant/bethke.pdf

[20] "Callisto: New Insights from Galileo Disk-Resolved UV Measurements." Hendrix, A. R., Johnson, R. E. The Astrophysical Journal, November 2008. http://people.virginia.edu/~rej/papers08/Hendrix-Johnson-ApJ08.pdf

Bio

Tom Kerwick is a multidisciplinary engineer and activist who currently works in microwave radio communications. He graduated with a Bachelor of Technology in Electronic Engineering in 1995, a Masters in Computer Systems in 1996, and more recently a Ph.D. in Engineering Technology in 2011.

MOSART: Modeling the Radiative Environment of Earth's Atmosphere, Terrain, Oceans, and Space

William M. Cornette
Computational Physics, Inc.

Abstract

This paper represents efforts over the past decade to develop a DoD computer application for predicting the radiative environment of the Earth's atmosphere, terrain, oceans, and space using first principle physics models and large environmental data bases constructed from satellite data and other sources. The Moderate Spectral Atmospheric Radiance and Transmittance (MOSART) code V2.0.4 is currently available, and the next release, Version 3.0, is in development. This presentation provides information on obtaining Version 2.0.4 and the current upgrades in Version 3.0, which is written in Fortran 2003, thereby allowing as many geometries, azimuths, and other variables as needed, with the smallest executable possible. MOSART V3.0 also executes faster than V2.0.4. It has the ability to produce a temporal variation on a series of observer-source geometries and includes a global soil composition and soil moisture database, a global land class database, additional molecular species, a smooth altitude transition for aerosol types, and a historical database of sunspot and solar activity. Future growth will include an enhanced terrain and ocean data from satellite remote sensing measurements, in addition to satisfying other user requirements.

Introduction

THE MODERATE SPECTRAL ATMOSPHERIC RADIANCE AND TRANSMITTANCE (MOSART) is a U.S. Department of Defense (DoD) standard computer code for calculating accurate and realistic atmospheric transmission and radiance along sensor-target line-of-sight paths and optical radiance backgrounds against which targets are detected by sensor systems. As such it has the capability to support both scene and signature simulations.

The job of a sensing device is to look for a signal from its target. The signal it receives depends upon the conditions of the atmosphere along the line-of-sight between it and the target, as well as the atmosphere surrounding the target. For example, how the atmosphere *transmits* the target's signal depends partly on the molecular structure of the intervening atmosphere. Molecules both absorb and scatter light differently for different spectral regions (hence our blue sky). Similarly, how the atmosphere *radiates* (provides signals not from the target) depends partly

on what else is nearby the target (*e.g.*, terrain or clouds), as well as the atmospheric properties (*e.g.*, temperature).

Consider a simplistic example: the eye (sensor) and a blue light bulb (target). The eye will see (sense) the light bulb when it is turned on at a given brightness (assuming the eye is looking towards the bulb). The atmosphere between the eye and bulb transmits the light radiating from the bulb to the eye along the line-of-sight. This is called radiative transfer. Let some dense fog get between the eye and the bulb, and the eye will not sense the same brightness (or even shape) as it did with no fog. The presence of the fog changes the make-up of the atmosphere between the eye and the bulb.

Now complicating things a bit, let the eye and bulb be close to the ground. Then the shape and type of the ground – its reflecting properties – also affects what the eye senses. If the ground is smooth, such as a water surface, then the reflected light off the ground can confuse the signal seen by the eye. Add a further complication: suppose there is an additional light bulb nearby, a red one. The eye wants to see the blue bulb. Somehow the extra red radiation must be subtracted from what the eye detects.

So this means that a comprehensive computer code to simulate what happens between a sensor and target will need to include many things such as the constitution of the atmosphere (temperatures, densities, molecules, and pressures) at various levels and resolutions; the structure of the ground; cloud cover; various line-of-sight geometries (*e.g.*, are there interfering structures between the sensor and target); and the response of the sensor to various spectral regions.

The MOSART code calculates atmospheric transmission and radiation over a wide spectral range: from the ultraviolet through the microwave spectral regions (wavelengths from 0.2 μm to infinity or frequencies from 0 to 50,000 cm^{-1}). It contains features extracted from the MODTRAN™ code developed by the Air Force's Phillips Laboratory [now Air Force Research Laboratory (AFRL)] and the Atmospheric Propagation and Radiative Transfer (APART) code developed by Photon Research Associates, Inc. (PRA). The AFRL code is widely used in many different atmospheric studies, both within and without the DoD. Since the PRA code was developed to provide atmospheric calculations for infrared (IR) signature studies of both targets and backgrounds, it has many features that are desirable for large simulation models. Because of the requirement that MOSART be compatible with the various codes used in the Synthetic Scene Generation Model (SSGM)[i], the overall structure of

this version of MOSART closely follows that of the PRA code. However, MOSART contains all of the AFRL code's atmospheric features and is easily used for that code's usual point-to-point calculations.

MOSART uses the same frequency band model and 1 cm^{-1} sampled (2 cm^{-1} resolution) band parameters database found in the AFRL code, which has been derived from the 1996 HITRAN line atlas of molecular spectral lines from which one can determine atmospheric absorption as a function of temperature and pressure. In the ultraviolet and visible regions, MOSART contains additional molecular absorption bands at a coarser resolution. The line-of-sight geometries include all of the AFRL geometries, plus some new geometries, including Observer-Source, Observer-Background, Observer-Source-Background, Earth Limb, Horizontal, and At-Source.

Recent development of MOSART was sponsored by the Missile Defense Agency (MDA).

History of MOSART

The history of MOSART began in the mid-1970s with the incorporation of LOWTRAN III[ii] into an airborne thermal infrared imaging sensor simulation. A significant number of changes were made to LOWTRAN to incorporate it into the simulation, and in the process, parts of the code were re-written to streamline the coding for faster execution. These modifications to LOWTRAN led, in 1979, to the development of a modular atmospheric code for both LOw spectral Resolution Atmospheric Propagation (LORAP) code and line-by-line HIgh spectral Resolution Atmospheric Propagation (HIRAP) code, which shared a significant amount of common code (*e.g.*, definition of the atmosphere, geometry, ray tracing). A ray tracing algorithm was also developed in the mid-1970s for calculating radar multipath and anomalous propagation, with numerical stability of better than one part in 10^6.

Starting in late 1980, LORAP morphed into the PRA code, which grew out of a merging of earlier atmospheric propagation and radiative transfer codes plus the addition of new capabilities and features while HIRAP was terminated. The PRA code was a 5 cm^{-1} spectral resolution code. Version 1.0 became the atmospheric portion of the Standard Infrared Radiation Model for plume signatures, that is, exhaust plumes from missiles and aircraft. It then grew under Defense Advanced Research Projects Agency (DARPA) funding such as the DARPA Teal Ruby program, a technology experiment to test new infrared sensors for early

warning satellites. It also received funding through a number of low observables aircraft programs (*e.g.*, the B-2 Stealth Bomber). Later versions of the PRA code provided support to the Generic Scene Simulation Software (GENESSIS) terrain scene simulation and the cloud scene simulation, CloudSim. It also supported a number of air, ground, and space-based target signature models, including the Target Signature Simulation, the Infrared Signature Analysis Model, and the Flexible Infrared Signature Toolkit.

This work finally resulted in the PRA Version 7.00 in 1988, when it was incorporated into the Strategic (now Synthetic) Scene Generation Model (SSGM) in 1991. SSGM had two atmospheric propagation codes, the PRA part and the AFRL part, each of which had its own purposes: the PRA part for supporting the target signature and background scene simulations, and the AFRL part for providing the line-of-sight calculations for the sensor. With the intent of making sure that the two provided similar results, MDA's predecessor, the Strategic Defense Initiative Organization, funded an effort through the Air Force's Phillips Laboratory to combine the capabilities of the two codes, resulting in the MOSART code.

The original MOSART was developed by PRA and delivered to the Air Force as Version 1.40. This version was released in 1995, when the developer of the code, Dr. William M. Cornette, left PRA to take a position with the Defense Mapping Agency (later merged into the National Imagery and Mapping Agency) as the Scientific Advisor for Defense Modeling and Simulation. The official public release of MOSART V1.40 was in mid-1996.

In 1997-98, PRA received funding from AFRL for some MOSART code testing, and independent verification and validation. During PRA's activities, Dr. Cornette supported PRA's work by responding to questions and modifying MOSART based on results from the testing. This work resulted in a series of releases as briefly described here.

V1.50 was released in 1997; modifications were in response to initial user feedback and preliminary PRA testing. V1.60 was released in 1998; modifications were based on the work by PRA. Some upgrades were made (*e.g.*, new aerosol models) to maintain consistency with the Air Force model. This is the version that is currently in SSGM. V1.65 was released in 2000; minor changes were made in the terrain material temperature prediction capability. However, this version was not implemented into SSGM.

V1.70 was released in 2005; significant changes were made in the terrain material temperature calculations. For example, the model for the direct and diffuse solar loading[iii] was completely replaced with a 27-band model, and the new model was validated. The model for the diffuse thermal loading was upgraded and components of the model were replaced. Multiple scattering, which was not part of the older model, was included. The solution of the equation of heat transfer was extensively revised. The new algorithm was considerably faster than the older algorithm, and a limited set of validations was performed. And the reflectivity databases for fresh water, concrete, asphalt, and wood were revised.

V2.00 was initially released in 2006, and later released in 2008. Several new utilities were developed, a number of new capabilities were added, which are discussed below. James H. Brown of the AFRL with the help of Carol I. Foley from Boston University, thoroughly tested V2.00, with final delivery of V2.00c provided to AFRL in January 2008. In July 2009, the responsibility for MOSART transitioned from AFRL to NRL, and a subsequent modification was made to fix a problem for geosynchronous sensor geometry calculations in late 2009, resulting in the current code, V2.0.4 (the change in the numbering format was requested by NRL).

In 2006, work began on V3.0, which is a Fortran 95 code with the capability to model the full four-dimensional (*i.e.*, latitude, longitude, altitude, and time) radiative environment. Although as of mid-2012, V3.0 is a working code, it is far from complete and a release date is still to be determined.

MOSART Code Features

The MOSART code includes a number of features and capabilities. For example, it uses an observables-driven architecture for multiple view path geometries, such as:

a. Observer-to-source radiative transfer
b. Observer-to-background radiative transfer
c. Full radiative environment
d. Solar, lunar, and planetary ephemerides[iv]
e. User-defined and analytical earthshine[v] and skyshine[vi]

In order to model the radiative environment, the code must be capable of fully characterizing the environment, including:

a. Global three-dimensional atmospheres (latitude, longitude, and altitude)
b. User-defined three-dimensional atmospheres
c. Scalable profiles (water vapor, carbon dioxide, ozone, haze)
d. Variable climatologies (temperature, humidity, wind)
e. Aerosols (boundary layer, troposphere, stratosphere, mesosphere)
f. Temperature-dependent background stratospheric aerosol model
g. Atmospheric-dependent haze profile
h. Smoke/soot in an elevated layer
i. Geographical dependence of boundary layer aerosol
j. Smooth transition of aerosol types with altitude
k. Hydrometeors (water clouds, ice clouds, cirrus, fog, rain, snow)
l. Broken cloud fields
m. Terrain scenes and materials (optical and thermal properties)
n. Average and line-of-sight (LOS) backgrounds
o. Space backgrounds

Once the environment has been fully characterized, a fully developed set of radiative transfer algorithms are used to predict the radiative environment, including:

a. AFRL code V3.7 band model and molecular absorption
b. Ultraviolet through millimeter wave (0 – 50,000 cm^{-1})
c. Correlated path treatment
d. Three-stream approximation for multiple scattering
e. Adjustable exponential sum fit (Malkmus-Laguerre and others)
f. Continuous grid approximations for layer model
g. Turbulence and sky noise
h. Forward in-scatter
i. Sensor spectral responses

To support the characterization of the atmosphere, a comprehensive set of databases for representation of atmosphere and terrain are required, including:

a. 23 model atmospheres with seasonal variations
b. Global boundary layer and tropospheric meteorological conditions
c. Concentrations for 50 molecular species

d. Global atmosphere model to calculate variations in atmospheric parameters along the line-of-sight
e. Climatological database to modify standard atmospheric models for a given location
f. Aerosol haze profiles and models
g. Cloud, rain, and fog (hydrometeors) models
h. Terrain altitude, ecosystem type, and fraction water and snow cover
i. Background models for terrain scenes, ocean, and space
j. Soil type, texture, composition, depth, and moisture content
k. Urban center locations
l. Population density

For the thermal components of the radiative transfer algorithms, it is necessary to predict the terrain material temperatures using broadband solar and thermal loading diurnal variations, and to compute the terrain surface temperature for selected surface materials.

A number of utilities are provided with MOSART, including a blackbody temperature converter, a spectral filter integration code, an illuminance (visual) converter, a floating point tester, a database installer, a binary to American Standard Code for Information Interchange (ASCII) file converter, and an input file creator. A number of codes are supported by MOSART, including a diurnal global terrain temperature code, a statistical scene generator, a hyperspectral sensor and target simulator, and a Mie scattering code for coated spheres.

MOSART Global Databases

An extensive set of global databases is incorporated into the MOSART V2.0 code, including climatologies, terrain elevation, water/snow compositions, ecosystem type, climatology atmospheric profiles from the earth's surface to the tropopause, and hydrology. Coupled with the ecosystem and terrain elevations are composite terrain scene types with appropriate boundary layer aerosol compositions. Each scene includes appropriate parameters for determining the terrain temperature for each material in the scene, together with the reflected and emitted radiances for determining the mean and standard deviation of the radiances for the scene. The global database model allows a full three-dimensional representation of the earth's atmosphere with radiative transfer varying as the line-of-sight moves within the spatially changing

atmosphere. The global databases described here are included with MOSART V2.0.

The MODTRAN™ V3.7 Molecular Database (1 cm^{-1}) includes, for each molecular specie, the molecular absorption coefficient, line density, line width, and line tails as a function of temperature and wavenumber.

The Global Climatology Database (4.5° latitude × nominal 4.5° longitude × month[vii]) contains the surface air temperature, a three-étage[viii] cloud cover and cloud radiance, cirrus cloud cover, snow cover, and land cover.

The Global Scene Database (10 arc-min × 10 arc-min) includes the altitude (see Figure 1), ecosystem (see Figure 2), and fraction ground water (see Figure 3).

The Global Hydrology Database (1° × 1° × month) includes monthly values of sea ice cover, snow cover, and sea surface temperature.

The Global Oceanic Database (15 arc-min × 15 arc-min x month) includes sea surface temperature (see Figure 4) and salinity (see Figure 5).

The Global Climatology Profile Database (5° × 5° × monthly) includes surface pressure, temperature and variance profiles, dew point and variance profiles, and wind (total, U-component, V-component) profiles.

In addition to these databases listed here, MOSART V3.0 includes a number of new global databases described later in this article.

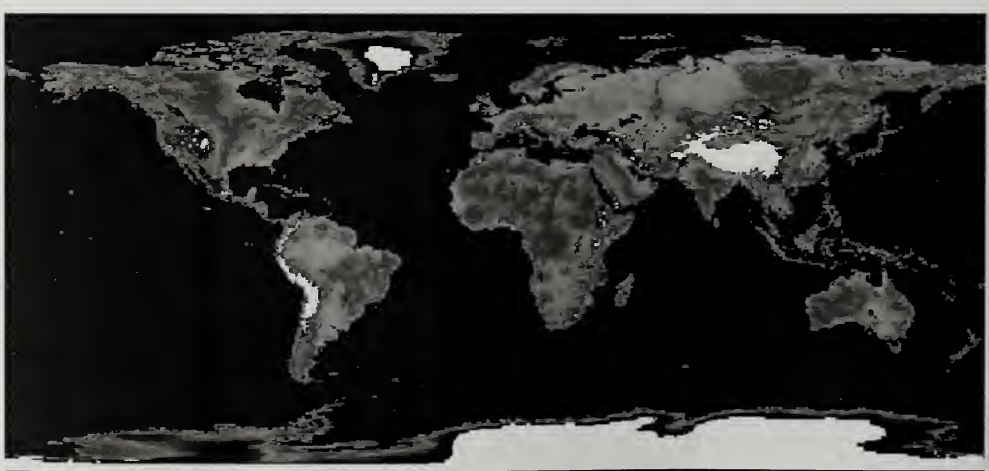

Figure 1. Terrain Altitude

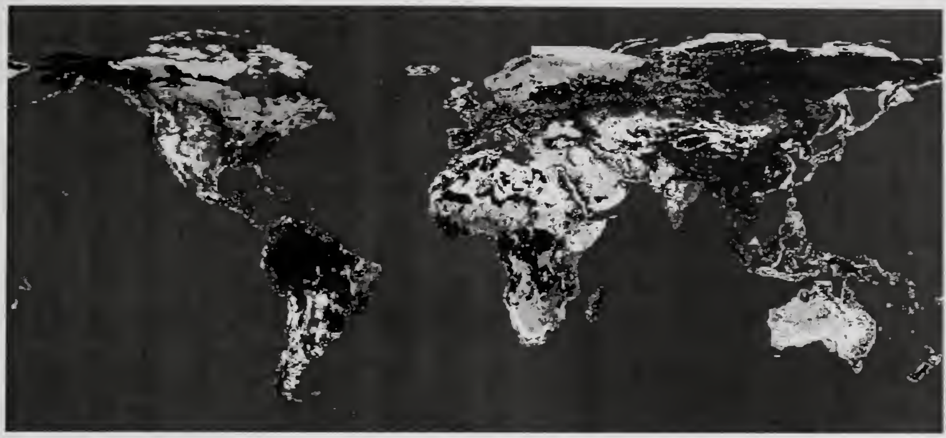

Figure 2. Ecosystems

Figure 3. Fraction Ground Water

MOSART V2.0.4 Capabilities

This section provides a partial list of upgrades in capability in MOSART V2.0.4 from the historical versions described earlier. The list is not meant to be exhaustive; it provides the significant upgrades, but not some of the minor ones.

Three-dimensional atmospheres (*i.e.*, latitude, longitude, and altitude variations) versus two-dimensional (*i.e.*, latitude and altitude variations) are allowed.

Global atmospheres are constructed, using a combination of the 23 model atmospheres and data from the Global Atmospheric Profile Database for the boundary layer and troposphere.

The addition of variable climatologies for temperature (cold/normal/hot), humidity (dry/normal/wet), and wind speed (calm/normal/windy) -- using statistics in the Global Atmospheric Profile Database -- is a user-selected option.

The addition of scalable profiles for water vapor (total precipitable water), ozone (Dobson units), carbon dioxide (ppmV), and aerosol optical depth is also a user-selected option.

The addition of an elevated smoke/soot layer is based on work by Dr. Stephen Carr, Defense Science and Technology Organisation in Australia.

Broken cloud cover can be defined so that a line-of-sight can be partially in sun and partially in shade. Clouds can be defined on a user-defined latitude/longitude grid with a mixture of cloud types.

In MOSART V2.0.4, several databases are added for the first time or improved. The Global Atmospheric Profile Database is improved for temperature, pressure, and humidity. Wind speed and direction is a function of altitude for the troposphere. The Global Hydrology Database is improved for snow cover, ice cover, and ice temperature. See Figure 4 for sea surface temperature, and Figure 5 for sea surface salinity. The Global Urban Area Database is added (for 288 urban areas). And the Terrain Material Database upgraded natural materials (soil and rocks, water, ice, and snow) and man-made materials.

Boundary layer aerosol types are assigned based on the ecosystem and wind conditions. Aerosol altitude profiles are smoothed to avoid discontinuities found in the Air Force code. Average and line-of-sight backgrounds are incorporated for adjacency effect calculations. A full set of time zones, including daylight saving time for the globe, is incorporated into the code. An expanded higher spectral resolution terrain material database is added to the existing database. Broadband solar and thermal diurnal loading calculations are modified and upgraded. Atmospheric cooling profiles are also added.

Several of the MOSART utilities are upgraded or created: FPTEST, the floating point test code, and INSTDB, which installs the databases, are more user-friendly. Using Microsoft® Access, a user-friendly MOSART input file creator was created with pull down menus and embedded notes; this capability is a prototype, pending feedback from users.

The exponential sum fitting routine now allows users to select

different methods of determining the fit. The model developed by Wiscombe and Evans is incorporated, as well as a multi-term Gauss-Laguerre quadrature in support of the Malkmus-Laguerre method. An additional method using a Laplace transform with Gauss-Laguerre quadrature and minimization for exponential sum fitting is being tested and should be released shortly.

An analytical model for earthshine and skyshine is included. This is based on work originally performed by Dr. David C. Roberts (Spectral Sciences, Inc.), with additions to provide an improved fit.

The spectral region of the code is extended to include a high resolution microwave/millimeter wave region in support of passive microwave radiometers.

All databases now automatically determine their required direct access record lengths, rather than having the user supply them.

The oxygen dimer, O_4, is added, with space created for the future addition of ethylene (C_2H_4), hypobromous acid (HOBr), and the hydroperoxyl radical (HO_2), along with space for a user-defined molecule, to be added in the near future.

The ephemeris time (see Figure 6) is currently updated through July 2012 with measured data; through June 2013 with refined predictions; and through 2014 with rough approximations. Additional information on how to obtain new measured data from the International Earth Rotation System website is included.

Multiple, overlapping filter spectral responses are allowed. A number of instrument spectral responses are delivered with the code, including Landsat, Satellite Pour l'Observation de la Terre (Spot), Advanced Very High Resolution Radiometer (AVHRR), Ikonos, and a generic set of responses.

Several numerical idiosyncrasies were corrected when found during the comparison of output files created on different machines. Detailed comparisons were made of the test case output files generated on a Linux® machine (the base line), a Windows® machine, and a Silicon Graphics Unix machine. The Linux® machine used the Lahey lf95 Fortran 95 compiler, Version 6.2. The Windows® machine used the Lahey lf95 Fortran 95 compiler, Version 7.1. The Silicon Graphics machine used the f95 compiler that is part of the operating system.

Figure 4. Sea Surface Temperature (January)

Figure 5. Sea Surface Salinity (January)

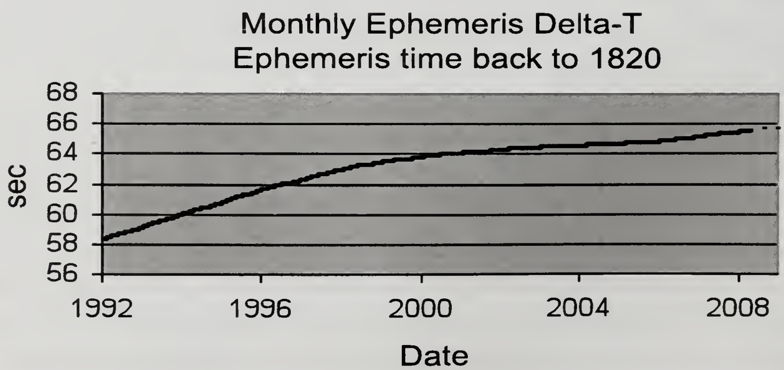

Figure 6. Delta-T for Ephemeris Time[ix]

Availability of MOSART Code and Documentation

MOSART V2.0 and its utility programs are written in American National Standards Institute X3.9-1978 FORTRAN (FORTRAN 77) with a few Fortran 95 and Mil-Std 1753 extensions. The code delivered with MOSART V2.0 includes:

- FPTEST: Tests machine dependent operations
- INSTDB: Installs direct access binary databases
- MOSART: Is the main MOSART program
- ASCBIN: Converts binary files to ASCII and vice-versa
- BBTEMP: Converts radiance to equivalent blackbody temperatures
- CRFILE: Assists in preparing the MOSART input files
- MRFLTR: Degrades the spectral output using a filter function
- VISUAL: Converts visible radiances to luminances and determines color

Four volumes of MOSART manuals for V2.0 provide users the ability to install and execute the code, technical background to assist with using the code, and information concerning to software itself. The volumes in the manuals include:

- Volume I: Installation Reference Manual
- Volume II: User Reference Manual
- Volume III: Technical Reference Manual
- Volume IV: Software Reference Manual

The Software Reference Manual is currently incomplete, although it contains a significant amount of information. It will be completed as resources permit.

Government responsibility for MOSART transitioned from AFRL to NRL in July 2009. Any questions concerning the status and future of MOSART can be sent to mosart@ssd5.nrl.navy.mil.

Version 2.0.4 can be obtained directly from Computational Physics, Inc. (CPI) at www.cpi.com/products/mosart.html, and interested parties are required to accept a downloadable software release agreement. CPI also offers comprehensive services using the MOSART code, including the development of databases modeling specified environments to meet the requirements of government programs and other users. Further information can be obtained by directly contacting the author at cornette@cpi.com.

New Capabilities in MOSART V3.0

MOSART V3.0 has been in development since mid-2006. As it currently exists, it already has a number of new capabilities, compared to V2.0.4. MOSART V3.0 has been extensively re-written (over 65%) in Fortran 95 in order to eliminate all COMMON blocks, make appropriate use of MODULEs, and use dynamic allocation in order to insure that the MOSART executable is an efficient, small code. Dynamic allocation also removes restrictions on the number of inputs. For example, MOSART V.2.0.4 is limited to 50 geometries, while MOSART V3.0 has no such limit.

Certain select capabilities, such as command line arguments, I/O error messages, and accessing the environment variables are implemented in Fortran 2003 and 2008; the GNU gfortran 4.6/4.7 compiler is used to compile MOSART V3.0.

MOSART V3.0 has been expanded into a full four-dimensional code, with each geometry being executed for a different time of day.

In addition to the databases listed earlier for V2.0.4, MOSART V3.0 includes additional new global databases. This currently includes the following (and other databases may be added during future development):

1. Food and Agriculture Organization (FAO) of the United Nations Global Soil Database ($1° \times 1°$), which includes 26 soil types at two-depth layers, texture, depth, and slope data (0-30 cm; 30-100 cm).

2. U.S. Department of Agriculture (USDA) Global Soil Database (5 arc-min × 5 arc-min), which includes soil type, bulk density, porosity, and water holding capacity. See Figures 7 and 8 for soil texture at the two depth layers. Figure 9 shows other soil properties.

3. USDA soil composition, including percentages of clay, sand, silt, organic matter, and coarse fragments (5 arc-min) as shown in Figure 10.

4. USDA Soil Moisture Database ($0.5° \times 0.5° \times$ monthly).

5. Global Population Density Database ($1° \times 1°$).

6. AVHRR land cover types ($1° \times 1°$); see Figure 11.

7. Expanded urban centers for over 1300 locations with population and area.
8. Default boundary layer aerosols.
9. Nighttime urban lights; see Figure 12 for lights and fires measured by the Defense Meteorological Satellites Program (DMSP) and Figure 13 for the MOSART Nighttime Urban Lights.
10. Light source spectra.
11. Sunspot activity; see Figure 14.
12. Solar radio fluxes (10.7 cm).
13. Geomagnetic indices (A_p).
14. Molecular databases (MODTRAN™ V4: 15 cm^{-1}, 5 cm^{-1}, 1 cm^{-1}, 0.1 cm^{-1}).

Other new capabilities include: the addition of planetary ephemerides; incorporation of a standard NRL model for defining the composition of the upper atmosphere (MSISE-00); and development of a new exponential sum fitting algorithm (Laplace/Gauss-Laguerre S-optimization) accompanied by removal of the Wiscombe-Evans algorithm. An improved terrain material temperature model, together with the creation of site-specific soil data has resulted in improved terrain representation.

The user also has the capability to interrogate databases independent of MOSART, together with over 18 new test cases to illustrate use of the additional capabilities.

Work is ongoing for MOSART V3.0. NRL is presently developing requirements for MOSART 3.0 that will add to the above capabilities. If the MOSART user community has definitive requests for specific capabilities, now is the time to let those needs be known.

Summary

This paper represents efforts of primarily the past decade to model the radiative environment of the Earth's atmosphere, terrain, oceans, and space for supporting the scene generation requirements of certain government programs. MOSART V2.0.4, together with appropriate databases and documentation, is currently available to the user community.

MOSART V3.0 is now expanded into a full four-dimensional radiative environment prediction tool. It currently exists as a working code, with a number of additional capabilities, and even more capabilities planned. Input from the MOSART user community is welcome regarding the addition of new capabilities for the code. The date for the availability of MOSART V3.0 is yet to be determined. Additional improvements, testing, validation and availability of MOSART V3.0 are dependent on continued support from the MDA Backgrounds Phenomenology program.

Figure 7. USDA Soil Textures (0 - 30 cm depth)

Figure 8. USDA Soil Textures (30 - 100 cm depth)

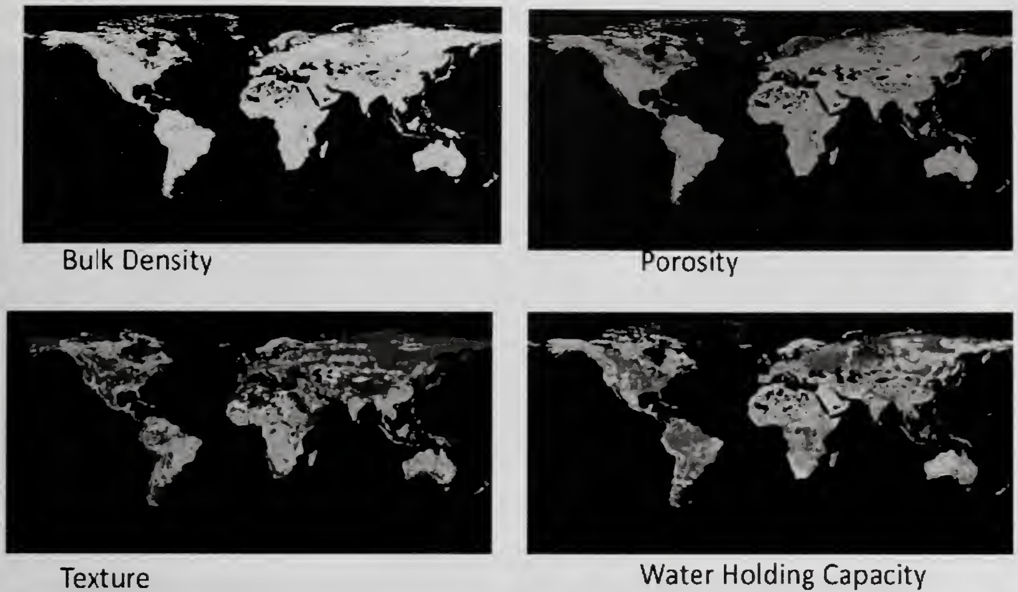

Figure 9. Soil Properties

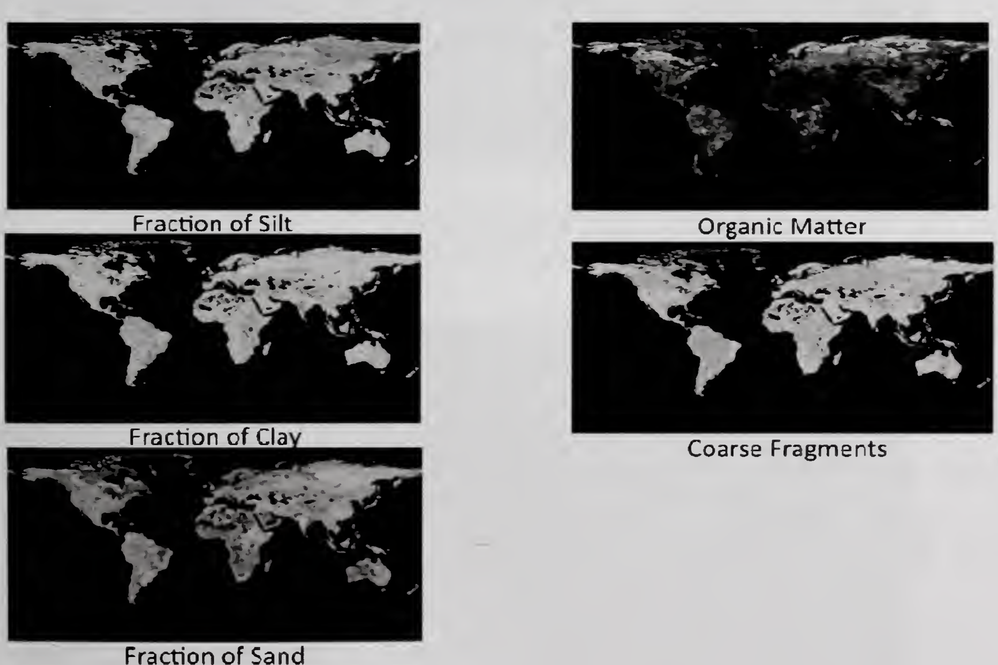

Figure 10. USDA Soil Composition (5 arc-min × 5 arc-min)

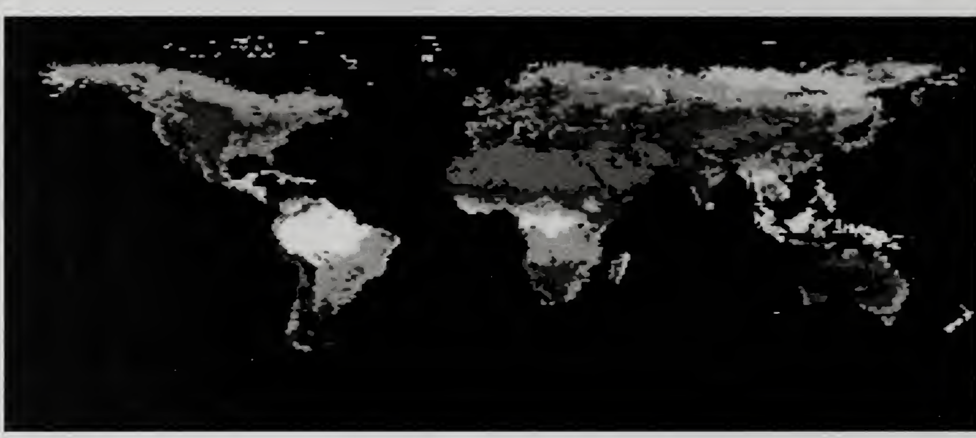

Figure 11. AVHRR Land Cover Classes (1° × 1°)

Figure 12. DMSP Nighttime Lights of the World (2006)

Figure 13. MOSART Nighttime Urban Lights

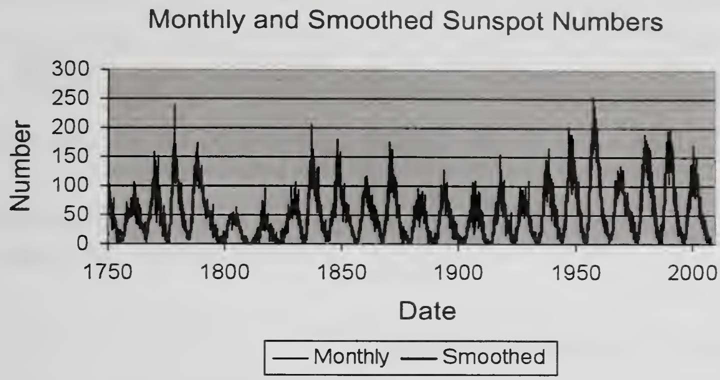

Figure 14. Monthly and Smoothed Sunspot Numbers

Acknowledgements

A number of individuals assisted the author in the development of MOSART over the years:

Photon Research Associates, Inc. (a subsidiary of the Raytheon Company)

- Sally D. Jandrall (for testing and evaluating early versions of the code)
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Naval Research Laboratory

- Kate Roach (for testing and patience)
- Dr. Eric P. Shettle (for discussions on aerosols)

Numerous others are also acknowledged for their feedback and patience.

Bio

Dr. Cornette is an internationally recognized expert in the modeling of atmospheric propagation and environmental effects. With over 40 years in government and industry, he has supported a number of aircraft and satellite programs. He is the author of MOSART and a number of other government standard codes.

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[i] The Synthetic Scene Generation Model (SSGM) is designed to integrate state-of-science knowledge, databases, and validated phenomenology models thereby serving as a traceable standard against which different concepts and designs can be evaluated.

[ii] A FORTRAN computer program, LOWTRAN III, calculates the transmittance of the atmosphere in the spectral region from 0.25 to 28.5 micrometers at a spectral resolution of 20/cm.

[iii] The amount of solar energy incident upon a surface that results in heating of the surface.

[iv] In computer codes an ephemeris is an algorithm for calculating the positions of the Sun, Moon, and planets.

[v] Earthshine is reflected and emitted earthlight.

[vi] Radiation scattered through the air.

[vii] Longitudinal resolution degrades as the latitude nears the poles until between 85.5° and 90° at both the North and South Poles the longitudinal resolution is 120°.

[viii] Etage = level.

[ix] Delta Time is the time difference obtained by subtracting Universal Time (UT) from Terrestrial Time (TT): ΔT=TT−UT.

Methods to derive the Einstein partial differential equation describing the ray optics and kinematics of his light ray path experiment with moving mirror

Albert Gerard Gluckman
University of Maryland

Abstract

The solution τ of the partial differential equation $\left(\partial_{x'} + \frac{v}{c^2-v^2}\partial_t\right)\tau = 0$ is the time transformation of the Lorentz Transformation derived in §3 of Einstein's 1905 discovery paper of special relativity. This equation is derived from the equation $\frac{1}{2}(\tau_0 + \tau_2) = \tau_1$ describing Einstein's thought experiment of a light ray path with moving mirror in his kinematical derivation of the coordinate transformations of special relativity. Considered here are the mathematical details of the derivation of his partial differential equation, first by using the chain rule of the differential calculus, and second by using the method of applying the Taylor series approximation to the first order (because of the homogeneity of space and time). The historical confluence of the Einstein differential operator and time transformation, derived by means of kinematics, is identical with the differential operator and time transformation derived by J. Larmor in 1900, derived through the electromagnetic theory of Maxwell. However, it was Einstein who conceived of the relativity of simultaneity in the absence of an aether.

Section 1. Introduction

THE 1905 EINSTEIN DISCOVERY PAPER [1] describing special relativity first considers the kinematics of a thought experiment of a light ray path with a light source and a mirror both fixed in coordinate system k uniformly moving relative to a parallel rest system K. The experimental setup is described in Section 3 of this paper. The goal of Einstein's paper was to reconcile Maxwell's equations for electricity and magnetism with the motion of electrons near the speed of light. As a consequence of this thought experiment, Einstein derived a partial differential equation (PDE) whose solution τ is the Lorentz time transformation. The Lorentz transformation (1892) is named after the Dutch physicist Hendrik Lorentz and is also known as the Lorentz–Fitzgerald transformation. It was the result of attempts by Lorentz and others to explain how the speed of light was observed to be independent of the reference frame, and to understand the symmetries of the laws of electromagnetism.

The way in which Einstein accomplished this derivation is described with the barest mathematical essentials. One can proceed with at least two methods based upon his original light path equation (equation (3) below) in a constructivist approach to fill in the missing steps to discover the time transformation. I show in detail how to derive his PDE using both methods. One might also apply the Leibniz method of the ratio of differentials. The partial differential equation I will develop is:

$$\frac{\partial \tau}{\partial x'} + \frac{v}{c^2 - v^2}\frac{\partial \tau}{\partial t} = 0$$

where c is the speed of light, v is the relative speed between the two reference frames, x' is the position of the mirror, and τ is the solution which turns out to be the Lorentz transformation. The shorthand notation for writing this equation is:

$$\left(\partial_{x'} + \tfrac{v}{c^2 - v^2}\partial_t\right)\tau = 0 \qquad (1)$$

which is a variant formulation of

$$\tfrac{1}{2}\partial_{x'}\left(\tau_0 + \tau_2\right) = \partial_{x'}\tau_1. \qquad (2)$$

Equation (2) describes Einstein's thought experiment with a light ray path in which an ideal mirror in system $k(\xi, \eta, \zeta)$ undergoes uniform translatory motion relative to a designated rest system $K(x,y,z)$. τ_0 is the time the light ray leaves the source; τ_1 is the time the light ray is reflected by the mirror at x'; τ_2 is the time the light ray returns. The discussion of the kinematic consequences of his thought experiment is found in §3 of his June 1905 discovery paper [1]. The end result of his kinematic analysis was the discovery of the Lorentz coordinate transformations

$$\xi = \frac{1}{q}(x - vt) \qquad \eta = y \qquad \zeta = z \qquad \tau = \frac{1}{q}\left(t - \frac{vx}{c^2}\right)$$

where $q = \sqrt{1 - v^2/c^2}$. You may have seen these written as follows:

$$t' = \gamma\left(t - \frac{vx}{c^2}\right) \quad x' = \gamma(x - vt) \quad y' = y \quad z' = z$$

where γ is the Lorentz factor. For this paper I use Einstein's coordinate systems k and K from his paper.

The integral form of equation (2) is:

$$\tfrac{1}{2}\left(\tau_0+\tau_2\right)=\tau_1. \tag{3}$$

Suppressing for convenience the transverse coordinates, the coordinate system of system *k* is (ξ,τ) and that of system *K* is (x,t).

The function

$$\tau=a\left(t-\frac{vx'}{c^2-v^2}\right);\quad x'=x-vt \tag{4}$$

is the solution of the PDE (equation (1)), and is the time transformation between systems *k* and *K*.

The derivation of the PDE is described in detail in Section 4 using the chain rule of the differential calculus, and in Section 5 using a first order approximation of the Taylor series employing a method using arrays. This latter procedure is a condensation of the first description of this method of arrays described by Gluckman [2] using two array arrangements. The application of this new array arrangement could be used to represent differential equations as arrays. A second version of the use of the Taylor series to derive the PDE is also shown in Section 6. Section 7 has a brief discussion concerning the amazing derivation, slightly earlier than Einstein, of the operator and the time transformation by J. Larmor from the viewpoint of Maxwell's electrodynamics. This is, however, merely a formal correspondence, since the philosophical underpinnings are quite different.

The goal of Einstein's paper was to construct a "consistent theory of electrodynamics of moving bodies based on Maxwell's theory for stationary bodies." He set forth the principle that the velocity of the propagation of light is "independent of the state of motion of the emitting body" and because there is no need in the electrodynamic equations for a stationary aether, it is superfluous because all inertial motion is relative.

It is one of the goals of this analysis, which is concerned with the kinematic study underpinning his follow-on electrodynamic analysis, to describe the methodology that can be applied to relating and deriving his partial differential equation, whose solution τ is the time transformation of special relativity. A secondary goal of this analysis is to show the earlier discovery by J. Larmor of Einstein's differential operator as well as the same for the time transformation. I am not the first to find this, as

evidenced by a remark in a letter to Larmor by his former student Ebeneezer Cunningham, but I will give some mathematical discussion.

Larmor did not conceive of the relativity of simultaneity, nor could he abandon his beautiful aether. Therefore, it seems that the discovery by Einstein of special relativity is the culmination of the 19th century by a bold genius.

Section 2. The origin of the coefficient *a* in the time transformation that is the solution of the Einstein PDE

The solution $\tau = \tau(x', t)$ of the PDE is a function that is linear in the coordinates x' and t because, as Einstein pointed out in §3 of his discovery paper, the coordinates of system k and system K are related by equations that "must be *linear* on account of the properties of homogeneity which we attribute to space and time." Therefore

$$\tau = at + bx'. \tag{5}$$

Taking the partial derivatives of equation (5) one gets

$$\partial_t \tau = a \qquad \text{and} \qquad \partial_{x'} \tau = b.$$

In the same way, taking the partial derivatives of the PDE, one with respect to t and the other with respect to x' yields

$$\partial_t \tau = \frac{v}{c^2 - v^2}.$$

Therefore

$$b = \frac{-v}{c^2 - v^2} \cdot a.$$

Therefore, substituting the value for b into equation (5) yields

$$\tau = a\left(t - \frac{vx'}{c^2 - v^2}\right) \tag{6}$$

which is the expression Einstein showed without showing how to derive it.

Section 3. Setup of the apparatus of the thought experiment

The setup for the thought experiment consists of two parallel axes, one in uniform motion relative to the other axis that is designated to be at rest. The system k is in motion relative to the system K. The ξ-axis of the system k is parallel to and has the same handedness as the x-axis of the rest system K. The point x' on the ξ-axis is the arbitrarily chosen location of a perpendicularly set ideal mirror on the ξ-axis and it faces the source at point A on the ξ-axis of a light ray. This arbitrarily chosen location of the point A may coincide with the origin of the ξ-axis as a special case in order to simplify the algebra describing the setup. We initialize the experimental setup by having the origins of the two systems k and K coincide.

The point x' (the fixed mirror location on the ξ-axis of the k system) is distinguished from the length $|x'| = +\sqrt{(x')^2} = \ell + |x_A|$ where x_A is the location of the light source. When the point x_A equals 0 (or in other words is identified with the point 0 at the origin of the coordinate system), the light ray source is then at the origin of the x-axis. In this case $|x'| = \ell$ which is the fixed distance between the light ray source and the ideal mirror that is at point x'. As Einstein remarked in his §3, the light source x_A can be placed at the time of emission at any point on the x-axis.

The point x' is, in general, located on the ξ-axis at a distance $\ell = \sqrt{(x' - A)^2}$ from the source of the light ray at point A. If the source point A of the light ray were located at the origin of the coordinate system k, A would be 0 and then $\ell = +\sqrt{(x')^2}$ at the initial instant of the thought experiment; and the length ℓ would remain constant as the idealization of a rigid length. Once chosen, the position x' on the ξ-axis is not influenced with the passage of time with respect to the ξ-axis itself. In other words, the position x' as well as the position A can be arbitrarily chosen, where as a consequence, the distance ℓ between the ideal mirror and the source of the light ray is constant.

The time τ on the ξ-axis is recorded in the moving k system on the k-clock. The time t is recorded on the x-axis in the rest system on the K-clock. Refer to the Appendix for diagrammatic descriptions of the kinematics of the light ray with moving mirror thought experiment.

Section 4. Derivation of $\partial_{x'}\tau + v\left(c^2 - v^2\right)^{-1} \cdot \partial_t \tau = 0$ using the chain rule of the differential calculus

I suppress the transverse coordinates y and z to simplify the original format of the equation of the light ray path with moving mirror which appears in §3 of the 1905 discovery paper. Equation (2) then takes the form

$$\frac{1}{2}\left[\tau(0,t) + \tau\left(0, t + \frac{x'}{c-v} + \frac{x'}{c+v}\right)\right] = \tau\left(x', t + \frac{x'}{c-v}\right). \tag{7}$$

Let the origins of the moving k system and the parallel system K, designated to be at rest, coincide at the start of the light ray path thought experiment. Let the light source A also coincide with these origins at the start of the thought experiment so that the coordinates are

$$\left(x'_A, t\right) = \left(\xi_A, \tau\right) = (0,0); \quad \tau_0(0,0) = 0.$$

This assignment simplifies equation (5), so that it can be expressed as $\frac{1}{2} \cdot \tau_2 = \tau_1$ or else as

$$\tfrac{1}{2} \cdot \tau\left(0, t_{A'}\right) = \tau\left(x'_B, t_B\right) \tag{8}$$

where with regard to equation (3), since $\tau_0 = 0$, the time recorded/measured on the t-clock of system K at the receiver after the reflected light ray has returned to the new location A', is

$$t_{A'} = \frac{x'}{c-v} + \frac{x'}{c+v} \tag{9}$$

and the time at the ideal mirror $\ell = \left|x'\right|$ units of distance removed from the light ray source is

$$t_B = \frac{x'}{c-v}. \tag{10}$$

The symbol B is the position of the mirror at time t_B mapped onto the x-axis. The symbol c designates the vacuum velocity of light propagation, and in special relativity is independent of coordinate handedness and of direction of light rays in space.

Applying the chain rule of the differential calculus to the terms in equation (6) yields

at point A': (sink of ray)

$$\frac{\partial\tau}{\partial x'}(0,t_{A'})=\frac{\partial\tau}{\partial x'_{A'}}\cdot\frac{\partial x'_{A'}}{\partial x'}+\frac{\partial\tau}{\partial t_{A'}}\cdot\frac{\partial t_{A'}}{\partial x'}=\left(\frac{1}{c-v}+\frac{1}{c+v}\right)\frac{\partial\tau}{\partial t_{A'}}$$

at point B: (reflecting mirror)

$$\frac{\partial\tau}{\partial x'}(x'_B,t_B)=\frac{\partial\tau}{\partial x'_B}\cdot\frac{\partial x'_B}{\partial x'}+\frac{\partial\tau}{\partial t_B}\cdot\frac{\partial t_B}{\partial x'}=\frac{\partial\tau}{\partial x'}+\frac{1}{c-v}\frac{\partial\tau}{\partial t_B}.$$

Substitution of these derivatives and the value $\tau_0=0$ into equation (2) where

$$\tau_1=\tau(x'_B,t_B)\quad\text{and}\quad\tau_2=\tau(0,t_{A'})$$

yields

$$\frac{1}{2}\left(\frac{1}{c-v}+\frac{1}{c+v}\right)\frac{\partial\tau}{\partial t_{A'}}=\frac{\partial\tau}{\partial x'}+\frac{1}{c-v}\frac{\partial\tau}{\partial t_B}. \tag{11}$$

Taking derivatives of $t_{A'}$ and t_B with respect to t

$$\frac{\partial t_{A'}}{\partial t}=\frac{\partial t_B}{\partial t}=1\quad\text{as do their reciprocals}\quad\frac{\partial t}{\partial t_{A'}}=\frac{\partial t}{\partial t_B}=1$$

and therefore

$$\frac{\partial\tau}{\partial t_{A'}}=\frac{\partial\tau}{\partial t}\cdot\frac{\partial t}{\partial t_{A'}}=\frac{\partial\tau}{\partial t}\cdot 1=\frac{\partial\tau}{\partial t}\quad\text{and}$$

$$\frac{\partial\tau}{\partial t_B}=\frac{\partial\tau}{\partial t}\cdot\frac{\partial t}{\partial t_B}=\frac{\partial\tau}{\partial t}\cdot 1=\frac{\partial\tau}{\partial t}.$$

Therefore, equation (9), after substitution and reduction yields Einstein's PDE, equation (1) which is shown above, and whose solution τ is the relativistic time transformation.

Section 5. Derivation of $\partial_{x'}\tau + v\left(c^2 - v^2\right)^{-1} \cdot \partial_t \tau = 0$ using the 1st order approximation of the Taylor series in 2 variables

This method was conceived in a most general formulation where no simplifying assumption is made about the location A of the emitter of the light ray source. Equation (3) can be arranged in a column format such that to each of its 3 functions τ_0, τ_2, and τ_1 (the ray path terms), there corresponds a linear function expressed as a first order Taylor series approximation (neglecting 2nd order and higher order terms) so that

$$
\begin{array}{ccc}
\textit{Ray path terms} & & \textit{Taylor Array} \\
\tau_1 & \sim & \text{a Taylor series approximation} \\
\| & & \| \\
\left|\begin{array}{c} \frac{1}{2}\tau_2 \\ + \\ \frac{1}{2}\tau_0 \end{array}\right| & \begin{array}{c} \sim \\ \\ \sim \end{array} & \left|\begin{array}{c} \text{a Taylor series approximation} \\ + \\ \text{a Taylor series approximation} \end{array}\right|
\end{array}
$$

This array is a representation of the differential equation, and this kind of representation should be applicable in general to other systems of differential equations. The summation of terms in this array with the substitutions $x' = H + h$ and $t = K + k$ leads to equation (1) which is the Einstein PDE.

Therefore, consider the linear approximation

$$\tau(H + h, K + k) = \tau(H, K) + h\partial_H \tau(H, K) + k\partial_K \tau(H, K) \tag{12}$$

where $H + h = x'$ and $K + k = t$. Upon substitution, equation (10) becomes

$$\tau(x', t) = \tau(H, K) + (x' - H)\partial_H \tau(H, K) + (t - K)\partial_K \tau(H, K) \tag{13}$$

Therefore, the following correspondences can be set up in the following array arrangement:

$$\begin{array}{ccccccc}
\tau(x',t_B) & \sim & \tau(H,K) & + & (x'-H)\partial_H\tau(H,K) & + & (t_B-K)\partial_K\tau(H,K) \\
\vdots & & & & \vdots & & \\
\hline
\frac{1}{2}\tau(0,t_A) & \sim & \frac{1}{2}\tau(H,K) & + & \frac{1}{2}(0-H)\partial_H\tau(H,K) & + & \frac{1}{2}(t_A-K)\partial_K\tau(H,K) \\
+ & & + & & + & & + \\
\frac{1}{2}\tau(0,t_{A'}) & \sim & \frac{1}{2}\tau(H,K) & + & \frac{1}{2}(0-H)\partial_H\tau(H,K) & + & \frac{1}{2}(t_{A'}-K)\partial_K\tau(H,K) \\
\hline
\end{array}$$

The array of my right side yields

$$x'\partial_H\tau(H,K) = -t_B\partial_K\tau(H,K) + \tfrac{1}{2}\cdot t_A\partial_K\tau(H,K) + \tfrac{1}{2}\cdot t_{A'}\partial_K\tau(H,K) \quad (14)$$

Now in the limit as h and k independently go asymptotically to zero

$$x'\partial_{x'}\tau(x',t) = -t_B\partial_t\tau(x',t) + \tfrac{1}{2}\cdot t_A\partial_t\tau(x',t) + \tfrac{1}{2}\cdot t_{A'}\tau(x',t) \quad (15)$$

which reduces to $x'\partial_{x'}\tau + (t_B - \tfrac{1}{2}\cdot t_A - \tfrac{1}{2}\cdot t_{A'})\partial_t\tau = 0$, which after substitution for t_B, t_A and $t_{A'}$, and reduction, yields

$$\partial_{x'}\tau + v\left(c^2 - v^2\right)^{-1}\cdot\partial_t\tau = 0 \quad (1)$$

which is Einstein's differential equation in his §3. The necessary and sufficient conditions that $\partial_H\tau(H,K) = \partial_{x'}\tau(x',t)$ and that $\partial_K\tau(H,K) = \partial_t\tau(x',t)$ are:

$$\partial_H \tau(H,K) = \lim_{h\to 0}\frac{\tau(H+h,K)-\tau(H,K)}{h} = \lim_{h\to 0,k\to 0}\frac{\tau(x',t-k)-\tau(x'-h,t-k)}{h}$$

$$= \lim_{h\to 0}\frac{\tau(x',t)-\tau(x'-h,t)}{h} = \partial_{x'}\tau(x',t)$$

$$\partial_K \tau(H,K) = \lim_{k\to 0}\frac{\tau(H,K+k)-\tau(H,K)}{k} = \lim_{k\to 0,h\to 0}\frac{\tau(x'-h,t)-\tau(x'-h,t-k)}{k}$$

$$= \lim_{k\to 0}\frac{\tau(x',t)-\tau(x',t-k)}{k} = \partial_t \tau(x',t)$$

Section 6. A second method applying the Taylor series 1st order approximation to derive the PDE

If the origins of the parallel *k* and *K* systems coincide at the start of the light ray path thought experiment (with the moving ideal mirror attached to system *k*), then $\tau_0 = \tau(0,0) = 0$, and equation (3) can be written as

$$\tfrac{1}{2}\cdot\tau_2 = \tfrac{1}{2}\cdot\tau\left(0+0,0+t_{A'}\right) = \tau\left(0+x'_B,0+t_B\right) \tag{16}$$

where the value of t is $t=0$ because the location A of the light ray emitter is at the coinciding origins of the parallel *k* and *K* systems at the start of the thought experiment. Equation 14 may be transcribed as

$$\frac{1}{2}\left(h_2\frac{\partial\tau}{\partial x'}+k_2\frac{\partial\tau}{\partial t}\right) = h_1\frac{\partial\tau}{\partial x'}+k_1\frac{\partial\tau}{\partial t}. \tag{17}$$

Therefore, because

$$h_2 = 0 \qquad k_2 = t_{A'} \qquad h_1 = x' \qquad k_1 = t_B$$

where $x'_B = x'$ is the location of the reflecting mirror at the time t_B of reflection (*i.e.*, $x'_B = ct_B$), x'_B in the *k* system maps onto $x = x'+vt_B$ in the *K* rest system – their numerical values are the same. Equation (15) can now be re-written as

$$\frac{t_{A'}}{2}\frac{\partial\tau}{\partial t} = x'\frac{\partial\tau}{\partial x'}+t_B\frac{\partial\tau}{\partial t} \tag{18}$$

which after substitution of equations (7) and (8), takes the form of equation (9), which reduces to the Einstein PDE, which is equation (1) shown above.

Section 7. Some concluding remarks

The evolution of Larmor's theory of electrodynamics occurred in three distinct stages that occurred in 1894/5, 1897/8, and in 1900. His underlying principles for these researches of his were first, reliance on the theory of a stationary elastic incompressible aether whose strain energy per unit volume was identified with the energy of the electromagnetic field; and second, the time being absolute Newtonian time, the same everywhere on any clock on any frame at any speed at any spatial orientation relative to the stationary aether.

In his 1900 book publication [3] Larmor developed his complete presentation of his theory in which he applied the chain rule in extending his version of Hertz's formulation of the two curl electromagnetic field equations (one known as Ampère's law and the other as Faraday's law) in order to develop a theory "To deduce Fresnel's law for moving media," with the Michelson-Morley null result in mind; but mainly to develop a dynamical theory of the electric and optical aether. The use of the chain rule in the Hertz-Maxwell curl equations presented by Einstein in the electrodynamic portion of his paper can also be transformed by means of the chain rule into equations expressing a system in motion. In the course of so doing, Larmor developed the differential operator

$$\partial_{x'} + \frac{v}{c^2}\varepsilon \cdot \partial_{t'} = \partial_{x'} + \frac{v}{c^2 - v^2}\partial_t \tag{19}$$

where

$$\varepsilon = \left(1 - \frac{v^2}{c^2}\right)^{-1} \quad \text{and} \quad t' = t$$

The relation (19) shows that the Einstein and the Larmor operator are identical.

Furthermore, Larmor also derived the time transformation ([3] see his ref. 4, ch. XI, p. 173)

$$t'' = t' - \frac{v}{c^2}\varepsilon x' = t - \frac{vx'}{c^2 - v^2} \quad \text{where} \quad t' = t. \tag{20}$$

Relation (20) shows that the time transformation derived by Einstein is the same as the time transformation derived by Larmor.

As a tool for those who would venture into his work, Larmor derived the substitution $\alpha = -v/c^2$ that he used, in §14, Part II, in order to eliminate two differential cross terms ∂_{xt} from a differential equation. The expression $t' = t + \alpha x$ in his earlier work on May 16, 1895 is the source for the value α.

Thus, one sees the identity of the Larmor time transformation developed from considerations involving electromagnetic theory, with the Lorentz time transformation as first developed by Einstein as the solution of his differential equation, equation (1) above, which Einstein derived solely on the basis of the kinematics of his ray path equation, equation (3) above.

References

1. A. Einstein, *Zur Elektrodynamik bewegter Körper/On the electrodynamics of moving Bodies*, Ann. der Phys. **17** (1905) 891; also, **The Principle of Relativity**, Dover Publications, Inc., 1952, NYC, and the **Collected Works of Albert Einstein**, Princeton University Press.
2. A. G. Gluckman, *The missing lines of calculations in Einstein's derivation of the Lorentz transformation*, Physics Essays **21**, 4 (2008) 1-3.
3. J. Larmor, **Aether and Matter**, Cambridge at the University Press, 1900. See also LoC call no. QC671.L32.

Appendix

List of assumed values applied to describe the light path experiment.

The examples shown in diagrams 1 and 2 depend upon the following assumed parameter values. Let x' be the point on the ξ-axis of system *k*, designating the ideal mirror.

$\ell = |x'| = +\sqrt{(x')^2} = 10\,\text{km}$; distance of ideal reflecting mirror from the light source. In general, $\ell = \sqrt{(x'-A)^2}$; $x' > A$, where A is any point on the ξ-axis. For illustration purposes, calculations are simplified when $A = 0$, as in these examples. The ideal mirror (set transversely to the direction of uniform motion) is fixed at the end of an ideal rigid rod.

$c \approx 3.0 \times 10^5$ km/sec; vacuum velocity of the propagation of light.

$v = \frac{1}{4}$ c $= 0.75 \times 10^5$ km/sec; velocity of the light source ensemble with attached ideal mirror in system *k*, relative to parallel rest system *K*.

$\tau_c = x'/c$; stationary time (independent of motion) of light ray path propagation from the source A to the ideal mirror at x' in system *k*.

Case when the ideal mirror moves towards the initial position *A* of the light ray emitter. Thus $x' = x - vt$.

Emission

$$t_A = 0 \quad \text{and} \quad t_B = \frac{x'}{c+v} = \frac{10}{3.75\times10^5} = 2.\bar{6}\times10^{-5}\ \text{sec}$$

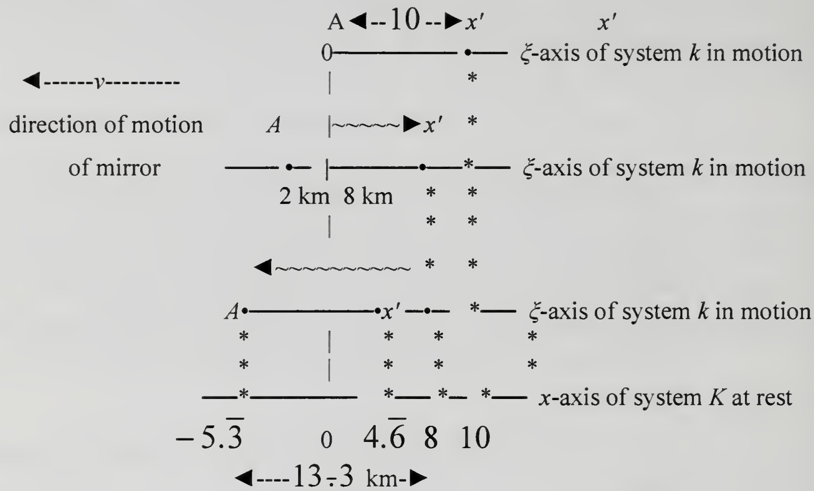
$$x = ct = 3(2.\bar{6}) = 8\ \text{km}$$

Reflection

$$t_{A'-B} = \frac{x'}{c-v} = \frac{10}{2.25\,x10^5} = 4.\bar{4}\times10^{-5}\ \text{sec}$$

$$x = ct = 3(4.\bar{4}) = 13.\bar{3}\ \text{km}$$

Diagram 1. The light ray ideal mirror/source ensemble on system k moves towards the initial position of the light ray emitter, relative to the parallel rest system K. Case of $x' = x - vt$.



<u>Case when the ideal mirror moves away from the initial position A of the light ray emitter. Thus $x = x' + vt$.</u>

Emission

$$t_B = \frac{x'}{c-v} = \frac{10}{2.25 \times 10^{-5}} = 4.\overline{4} \times 10^{-5} \text{ sec}$$

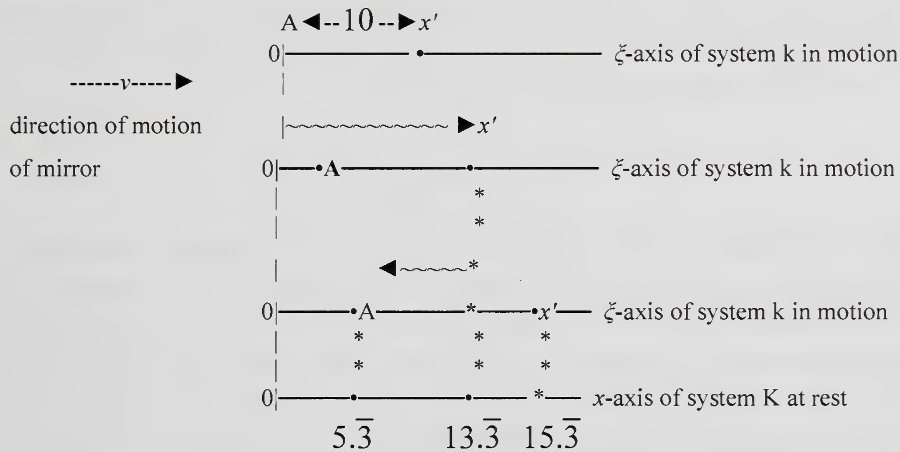
$$x = ct = 13.\overline{3} \text{ km}$$

Reflection

$$t_{A'-B} = \frac{x'}{c+v} = \frac{10}{3.75 \times 10^{-5}} = 2.\overline{6} \times 10^{-5} \text{ sec}$$

$$x = ct = 3\left(2.\overline{6}\right) = 8 \text{ km}$$

Diagram 2. The light ray mirror/source ensemble on system k moves away from the initial position of the light ray emitter, relative to the parallel rest system K. Case of $x = x' + vt$.



<u>Comparison of numerical results from the light ray path calculations based upon geometry vis à vis the time transformation equation, when the ideal mirror moves towards the emitter.</u>

$$\tau_1 = t_B - \frac{(-v)x'}{c^2 - v^2} = t_B + \frac{vx'}{c^2 - v^2}$$

$$= 2.\bar{6}\times10^{-5} + \frac{0.75\times10^{5}(10)}{(9.0-0.5625)\times10^{10}} = 3.\bar{5}\times10^{-5} \text{ sec}$$

The total distance travelled by the light ray is

$$13.\bar{3}\,\text{km} + 8\,\text{km} = 21.\bar{3}\,\text{km}$$

The total time for the passage of the light ray from the emitter to reflector to the last position of the emitter is $21.\bar{3}/c = 7.\bar{1}\times10^{-5}$ sec, and

$$0.5\left(7.\bar{1}\times10^{-5}\right) = 3.\bar{5}\times10^{-5} \text{ sec}$$

in agreement with the value computed from the time transformation.

Furthermore

$$t_{A'} = \frac{x'}{c-v} + \frac{x'}{c+v} = 7.\overline{1} \times 10^{-5} \text{ sec}$$

which is the total time required for the light ray to travel from the emitter to the moving mirror, and be reflected back to the new and last location of the emitter (now the point of reception) relative to the x-axis of the rest system K, regardless of whether the assembly is moving away from or towards the initial position of the emitter.

Bio

Dr. Gluckman is the author of seven monographs published by the Washington Academy of Sciences. They cover the evolution of electrical experiments over a 200 year period. He has also published 32 peer reviewed papers in many journals including the Proc. IEEE, the Am. J. Physics, and the Matrix and Tensor Quarterly. He prepared a replica typescript for the Joseph Henry papers of the Smithsonian that used the written notes of Henry on oscillatory current (1836 – 1842). He also worked with NASA and DoD on edge diffraction and multiple reflections of microwaves over terrain.

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BRIMMER, ANDREW F. (Dr.) Suite 302, 4400 MacArthur Blvd., NW, Washington DC 20007 (F)

BRISKMAN, ROBERT D. (Mr.) 61 Valerian Court, North Bethesda MD 20852 (F)

BROGAN, KEVIN (Dr.) 2933 Cherry St, Falls Church VA 22042 (M)

BROWN, LEWIS R. (Dr.) US EPA, Mailcode: 7507P, 1200 Pennysylvania Avenue, Washington DC 20704 (M)

CERF, VINTON G. (Dr.) 1435 Woodhurst Blvd., McLean VA 22102-2234 (F)

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CHUBIN, DARYL E. (Dr.) 1200 New York Ave, NW, Washington DC 20005 (F)

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COLE, JAMES H. (Mr.) 9709 Katie Leigh Ct, Great Falls VA 22066-3800 (F)

COUNTS, CLEMENT (Dr.) Biology Department Salisbury University, Salisbury DE 21801 (M)

CRISPIN, KATHERINE (Dr.) Geophysical Laboratory, Carnegie Institution of Washington, 5251 Broad Branch Dr NW, Washington DC 20015 (M)

CURRIE, S.J., CHARLES L. (Rev.) Jesuit Community, Georgetown University, Washington DC 20057 (EF)

DANCKWERTH, DANIEL 419 Beach Drive, Annapolis MD 21403-3906 (M)
DAVIS, ROBERT E. (Dr.) 1793 Rochester Street, Crofton MD 21114 (F)
DEAN, DONNA (Dr.) 367 Mound Builder Loop, Hedgeville WV 25427-7211 (F)
DEDRICK, ROBERT L. (Dr.) 21 Green Pond Rd, Saranac Lake NY 12983 (EF)
DIMITOGLOU, GEORGE (Dr.) 11053 Seven Hill Lane, Potomac MD 20854 (M)
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DONALDSON, JOHANNA B. (Mrs.) 3020 North Edison Street, Arlington VA 22207 (EF)
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DUNCOMBE, RAYNOR L. (Dr.) 1804 Vance Circle, Austin TX 78701 (EF)
DURRANI, SAJJAD (Dr.) 17513 Lafayette Dr, OLNEY MD 20832 (EF)
EDINGER, STANLEY EVAN (Dr.) Apt #1016, 5801 Nicholson Lane, North Bethesda MD 20852 (EM)
EGENRIEDER, JAMES A. (Dr.) 1615 North Cleveland Street, Arlington VA 22201 (F)
EPHRATH, ARYE R. (Dr.) 5467 Ashleigh Rd., Fairfax VA 22030 (M)
ERICKSON, TERRELL A. (Ms.) 4806 Cherokee St., College Park MD 20740-1865 (M)
ETTER, PAUL C. (Mr.) 16609 Bethayres Road, Rockville MD 20855 (F)
EVANS, HEATHER (Dr.) Apt 419, 1727 Massachusetts Ave NW, Washington DC 20036 (M)
FARMER, ROBERT F. (Dr.) Akzo Nobel Inc, 525 W Van Buren St., Ste. 1600, Chicago IL 60607-3835 (F)
FASANELLI, FLORENCE (Dr.) 4711 Davenport Street, Washington DC 20016 (F)
FAULKNER, JOSEPH A. (Mr.) 2 Bay Drive, Lewes DE 19958 (F)
FERNANDEZ, JEFFREY E. (Dr.) 8937 Garden Gate Dr., Fairfax VA 22031 (M)
FINKELSTEIN, ROBERT (Dr.) 11424 Palatine Drive, Potomac MD 20854-1451 (M)
FORZIATI, ALPHONSE F. (Dr.) 65 Heritage Dr, Unit 6, Cleveland GA 30528 (EF)

FRANKLIN, JUDE E. (Dr.) 7616 Carteret Road, Bethesda MD 20817-2021 (F)

FRASER, GERALD (Dr.) 5811 Cromwell Drive, Bethesda MD 20816 (M)

FREEMAN, ERNEST R. (Mr.) 5357 Strathmore Avenue, Kensington MD 20895-1160 (LEF)

FREEMAN, HARVEY 1503 Sherwood Way, Eagan MN 55122 (F)

FREHILL, LISA (Dr.) 1239 Vermont Ave NW #204, Washington DC 20005-3643 (M)

GAUNAURD, GUILLERMO C. (Dr.) 4807 Macon Road, Rockville MD 20852-2348 (EF)

GEBBIE, KATHARINE B. (Dr.) Physics Laboratory, National Institute of Standards and Technology, 100 Bureau Drive, MS 8400, Gaithersburg MD 20899-8400 (F)

GHAFFARI, ABOLGHASSEM (Dr.) 13129 Chandler Blvd, Sherman Oaks CA 91401-6040 (LF)

GIBBON, JOROME (Mr.) 311 Pennsylvania Avenue, Falls Church VA 22046 (F)

GIBBONS, JOHN H. (Dr.) Resource Strategies, P.O. Box 379, The Plains VA 20198 (EF)

GIFFORD, PROSSER (Dr.) 59 Penzance Rd, Woods Hole MA 02543-1043 (F)

GLUCKMAN, ALBERT G. (Mr.) 18123 Homeland Drive, Olney MD 20832-1792 (EF)

GORDON, NANCY M Associate Director for Strategic Planning and Innovation, US Census Bureau, HQ Rm: 8H128, Washington DC 20233 (F)

GRAY, JOHN E. (Mr.) PO Box 489, Dahlgren VA 22448-0489 (M)

GRAY, MARY (Professor) Department of Mathematics, Statistics, and Computer Science, American University, 4400 Massachusetts Avenue NW, Washington DC 20016-8050 (F)

GRIFO, FRANCESCA (Dr.) Union of Concerned Scientists, 1825 K St NW, Suite 800, Washington, DC 20006 (M)

GROVES, ROBERT M (Dr.) US Census Bureau, 4600 Silver Hill Hoad, Washington DC 20233 (M)

GROW, MARGARET E (Miss) 1000 Hilltop Circle, Baltimore MD 21250 (M)

HAAPALA, KENNETH (Mr.) 9638 Boyett Court, Fairfax VA 22032 (M)

HACK, HARVEY (Dr.) Northrop Grumman Corp., Ocean Systems MS 9105, PO Box 1488, Annapolis MD 21404-1488 (F)

HACSKAYLO, EDWARD (Dr.) 7949 N Sendero Uno, Tucson AZ 85704-2066 (EF)

HAIG, SJ, FRANK R. (Rev.) Loyola College, 4501 North Charles St, Baltimore MD 21210-2699 (F)

HARR, JAMES W. (Mr.) 180 Strawberry Lane, Centreville MD 21617 (EF)

HAYNES, ELIZABETH D. (Mrs.) 7418 Spring Village Dr., Apt. CS 422, Springfield VA 22150-4931 (EM)

HAZAN, PAUL 14528 Chesterfield Rd, Rockville MD 20853 (F)

HEANEY, JAMES B. 6 Olive Ct, Greenbelt MD 20770 (M)

HERBST, ROBERT L. (Mr.) 4109 Wynnwood Drive, Annadale VA 22003 (LF)

HEYER, W. RONALD (Dr.) MRC 162, PO Box 37012, Smithsonian Institution, Washington DC 20013-7012 (F)

HIBBS, EUTHYMIA D. (Dr.) 7302 Durbin Terrace, Bethesda MD 20817 (M)

HIETALA, RONALD (Dr.) 6351 Waterway Drive, Falls Church VA 22044-1322 (M)

HILL II, RICHARD E. (Mr.) 4360 Lee Hwy #204, Arlington VA 22207 (M)

HOFFELD, J. TERRELL (Dr.) 11307 Ashley Drive, Rockville MD 20852-2403 (F)

HOLLAND, PH.D., MARK A. 201 Oakdale Rd., Salisbury MD 21801 (M)

HOLLINSHEAD, ARIEL (Dr.) 23465 Harbor View Rd. #622, Punta Gorda FL 33980-2162 (EF)

HONIG, JOHN G. (Dr.) 7701 Glenmore Spring Way, Bethesda MD 20817 (LF)

HORLICK, JEFFREY (Mr.) 8 Duvall Lane, Gaithersburg MD 20877-1838 (M)

HOROWITZ, EMANUEL (Dr.) Apt 618, 3100 N. Leisure World Blvd, Silver Spring MD 20906 (EF)

HOROWITZ, SHARYN (Ms.) 217 Katie Court, Falls Church VA 22046 (M)

HOWARD, SETHANNE (Dr.) 5526 Green Dory Lane, Columbia MD 21044 (LF)

HOWARD-PEEBLES, PATRICIA (Dr.) 323 Wrangler Dr., Fairview TX 75069 (EF)

HURDLE, BURTON G. (Dr.) 3440 South Jefferson St., Apt. 356, Falls Church VA 22041 (F)

HWANG, JEESEONG (Dr.) 11408 Saddleview Place, North Potomac MD 20899 (M)
IKOSSI, KIKI (Dr.) 6275 Gentle LN, Alexandria VA 22310 (F)
IZADJOO, MINA (Dr.) 15713 Thistlebridge Drive, Rockville MD 20853 (M)
JACOX, MARILYN E. (Dr.) 10203 Kindly Court, Montgomery Village MD 20886-3946 (F)
JARRELL, H. JUDITH (Dr.) 9617 Alta Vista Ter., Bethesda MD 20814 (F)
JENSEN, ARTHUR S. (Dr.) Apt. 1104, 8820 Walther Blvd, Parkville MD 21234-9022 (LF)
JOHNSON, EDGAR M. (Dr.) 1384 Mission San Carlos Drive, Amelia Island FL 32034 (LF)
JOHNSON, GEORGE P. (Dr.) 3614 34th Street, N.W., Washington DC 20008 (EF)
JOHNSON, JEAN M. (Dr.) 3614 34th Street, N.W., Washington DC 20008 (EF)
JONG, SHUNG-CHANG (Dr.) 8892 Whitechurch Ct, Bristow VA 20136 (LF)
JORDANA, ROMAN DE VICENTE (Dr.) Batalla De Garellano, 15, Aravaca, 28023, Madrid , Spain (EF)
KADTKE, JAMES (Dr.) Apt. 824, 1701 16th St. NW, Washington DC 20009-3131 (M)
KAHN, ROBERT E. (Dr.) 909 Lynton Place, Mclean VA 22102 (F)
KARAM, LISA (Dr.) 8105 Plum Creek Drive, Gaithersburg MD 20882-4446 (F)
KATEHAKIS, MICHAEL N (Dr.) Apt. 1218, 200 Winston Dr., Cliffside Park NJ 07010-3219 (M)
KATEHAKIS, MICHAEL N. (Dr.) 200 Winston Dr. #1218, Cliffside Park NJ 07010 (M)
KATZ, ROBERT (Dr.) 16770 Sioux Lane, Gaitherburg MD 20878-2045 (F)
KAY, PEG (Ms.) 6111 Wooten Drive, Falls Church VA 22044 (LF)
KEEFER, LARRY (Dr.) 7016 River Road, Bethesda MD 20817 (F)
KEISER, BERNHARD E. (Dr.) 2046 Carrhill Road, Vienna VA 22181-2917 (LF)
KENNEDY, SEAN (Mr.) 2258 Cathedral Ave. NW, Washington DC 20008 (M)
KENNEDY, WILLIM G. (Dr.) 9812 Ceralene Drive, Fairfax VA 22032-1734 (M)

KLINGSBERG, CYRUS (Dr.) 1318 Deerfield Drive, State College PA 16803 (EF)
KLOPFENSTEIN, REX C. (Mr.) 4224 Worcester Dr., Fairfax VA 22032-1140 (LF)
KOWTHA, VIJAY (Dr.) 4555 Overlook Ave SW, Washington DC 20375 (M)
KRUEGER, GERALD P. (Dr.) Krueger Ergonomics Consultants, 4105 Komes Court, Alexandria VA 22306-1252 (M)
KRUGER, JEROME (Dr.) 1801 E. Jefferson St. Apt 241, Rockville MD 20852 (EF)
LANDREVILLE, NANCY M (Dr.) 5302-L Talladega Court, Frederick MD 21703 (M)
LANDWEHR, JURATE MACIUNAS (Dr.) 1923 Kenbar Ct., McLean VA 22101 (M)
LANHAM, CLIFFORD E. (Mr.) P.O. Box 2303, Kensington MD 20891 (F)
LAWSON, ROGER H. (Dr.) 10613 Steamboat Landing, Columbia MD 21044 (EF)
LECKRONE, DAVID (Dr.) 10903 Rocky Mount Way, Silver Spring MD 20902 (M)
LEIBOWITZ, LAWRENCE M. (Dr.) 3903 Laro Court, Fairfax VA 22031 (LF)
LEMKIN, PETER (Dr.) 148 Keeneland Circle, North Potomac MD 20878 (EM)
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LEWIS, DAVID C. (Dr.) 27 Bolling Circle, Palmyra VA 22963 (F)
LEWIS, E. NEIL (Dr.) Malvern Instruments, Suite 300, 7221 Lee Deforest Dr, Columbia MD 21046 (M)
LIANG, CHUNLEI (Dr.) MAE, 801 22nd Street NW, Washington DC 20052 (M)
LIBELO, LOUIS F. (Dr.) 9413 Bulls Run Parkway, Bethesda MD 20817 (LF)
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LING, LEE (Mr.) 1608 Belvoir Drive, Los Altos CA 94024 (EF)
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LYON, HARRY B. (Mr.) 7722 Northdown Road, Alexandria VA 22308-1329 (M)

LYONS, JOHN W. (Dr.) 7430 Woodville Road, Mt. Airy MD 21771 (EF)

MACHLIS, GARY (Dr.) Science Advisor to the Director, National Park Service, 1849 C Street, NW, Washington DC 20240 (M)

MAFFUCCI, JACQUELINE (Dr.) 1619 Hancock Ave, Alexandria VA 22301 (M)

MALCOM, SHIRLEY M. (Dr.) 12901 Wexford Park, Clarksville MD 21029-1401 (F)

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MCNEELY, CONNIE L. (Dr.) School of Public Policy, George Mason University, 3351 Fairfax Dr. Stop 3B1, Arlington VA 22201 (M)

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MIRIEL, VICTOR (Dr.) Salisbury University, Dept. of Biological Sciences, 1101 Camden Ave, Salisbury MD 21801 (M)
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PAZ, ELVIRA L. (Dr.) 172 Cook Hill Road, Wallingford CT 06492 (LEF)

PICKHOLTZ, RAYMOND L. (Dr.) 3613 Glenbrook Road, Fairfax VA 22031-3210 (EF)

PLESCIA, JEFFREY (Dr.) Applied Physics Laboratory, The Johns Hopkins University, MS 200-W230 11100 Johns Hopkins Road, Laurel MD 20723-6099 (M)

POLAVARAPU, MURTY 10416 Hunter Ridge Dr., Oakton VA 22124 (LF)

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PRIBRAM, KARL (Dr.) PO Box 679, Warrenton VA 20188 (EM)

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RADER, CHARLES A. (Mr.) 1101 Paca Drive, Edgewater MD 21037 (EF)

RAMAKER, DAVID E. (Dr.) 6943 Essex Avenue, Springfield VA 22150 (F)

RAVITSKY, CHARLES (Mr.) 37129 Village 37, Camarillo CA 93012 (EF)

READER, JOSEPH (Dr.) National Institute of Standards and Technology, 100 Bureau Drive, MS 8422, Gaithersburg MD 20899-8422 (F)

REDISH, EDWARD F. (Prof.) 6820 Winterberry Lane, Bethesda MD 20817 (F)

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REISCHAUER, ROBERT (Dr.) 5509 Mohigan Rd, Bethesda MD 20816 (F)

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RICH, PAUL (Dr.) 1527 New Hampshire Avenue, NW, Washington DC 20036 (M)

RICKER, RICHARD (Dr.) 12809 Talley Ln, Darnestown MD 20878-6108 (F)

RIDGELL, MARY P.O. Box 133, 48073 Mattapany Road, St. Mary's City MD 20686-0133 (LM)
RIGAUD, TAMARA M. (Ms.) 3509 Split Rail Lane, Ellicott City MD 21042 (M)
ROBERTS, SUSAN (Dr.) Ocean Studies Board, Keck 752, National Research Council, 500 Fifth Street, NW, Washington DC 20001 (F)
ROGERS, KENNETH (Dr.) 355 Fellowship Circle, Gaithersburg MD 20877 (M)
ROOD, SALLY A (Dr.) PO Box 426, Clifton VA 20124-0426 (F)
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RUBIN, VERA C (Dr.) 3308 McKinley NW, Washington DC 20015 (M)
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SEVERINSKY, ALEX J. (Dr) 4707 Foxhall Cres NW, Washington DC 20007-1064 (EM)
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SHAW, JINESH (Mr.) 1111 Arlington Blvd, Arlington VA 22209 (M)
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SHROPSHIRE, JR, W. (Dr.) Apt. 426, 300 Westminster Canterbury Dr., Winchester VA 22603 (LF)
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SOBIN, JAKE (Mr.) Marine Technology Society, 1100 H St. NW, Suite LL-100, Washington DC 20005 (M)
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SYKES, ALAN O. (Dr.) 304 Mashie Drive, Vienna VA 22180 (EM)
TABOR, HERBERT (Dr.) NIDDK, LBP, Bldg. 8, Rm. 223, National Institutes of Health, Bethesda MD 20892-0830 (M)
TAYSING-LARA, MONICA (Ms.) 3343 Dent Place NW, Washington DC 20007 (M)
TEICH, ALBERT H. (Dr.) PO Box 309, Garrett Park MD 20896 (EF)

THAYER, MYRA LYNN KOOPS (Ms.) 2073 Golf Course Dr., Reston VA 22030 (M)

THOMPSON, F. CHRISTIAN (Dr.) 6611 Green Glen Ct, Alexandria VA 22315-5518 (LF)

TIDMAN, DEREK A. (Dr.) 6801 Benjamin St., McLean VA 22101-1576 (M)

TIMASHEV, SVIATOSLAV (SLAVA) A. (Mr.) 3306 Potterton Dr., Falls Church VA 22044-1603 (F)

TOUWAIDE, ALAIN Department of Botany - MRC 166, National Museum of Natural History, PO Box 37012, Washington DC 20013-7012 (LF)

TOWNSEND, LEWIS R. (Dr.) 8906 Liberty Lane, Potomac MD 20854 (M)

TOWNSEND, MARJORIE R. (Mrs.) 3529 Tilden Street, NW, Washington DC 20008-3194 (LF)

TRAN, NICK (Dr.) Suite 300, 6363 Walker Lane, Alexandria VA 22310 (M)

TROXLER, G.W. (Dr.) PO Box 1144, Chincoteague VA 23336-9144 (F)

TURGEON, DONNA (Dr.) 8701 Running Fox Ct., Fairfax Station VA 22039 (M)

TYLER, PAUL E. (Dr.) 1023 Rocky Point Ct. N.E., Albuquerque NM 87123-1944 (EF)

UBELAKER, DOUGLAS H. (Dr.) Dept. of Anthropology, National Museum of Natural History, Smithsonian Institution, Washington DC 20560-0112 (F)

UHLANER, J.E. (Dr.) 5 Maritime Drive, Corona Del Mar CA 92625 (EF)

UMPLEBY, STUART (Professor) The George Washington University, 2033 K St NW, S. 230, Washington DC 20052 (F)

VAISHNAV, MARIANNE P. (Ms.) P.O. Box 2129, Gaithersburg MD 20879 (LF)

VAN TUYL, ANDREW (Dr.) 3618 Littledale Road, Apt. 203, Kensington MD 20895-3434 (EF)

VARADI, PETER F. (Dr.) Apartment 1606W, 4620 North Park Avenue, Chevy Chase MD 20815-7507 (EF)

VAVRICK, DANIEL J. (Dr.) 10314 Kupperton Court, Fredricksburg VA 22408 (F)

VIZAS, CHRISTOPHER (Dr.) 504 East Capitol Street, NE, Washington DC 20003 (M)

WALDMANN, THOMAS A. (Dr.) 3910 Rickover Road, Silver Spring MD 20902 (F)
WALLER, JOHN D. (Dr.) 5943 Kelley Court, Alexandria VA 22312-3032 (M)
WAYNANT, RONALD W. (Dr.) 6525 Limerick Court, Clarksville MD 21029 (F)
WEBB, RALPH E. (Dr.) 21-P Ridge Road, Greenbelt MD 20770 (F)
WEGMAN, EDWARD J. (Dr.) GMU Center Computer Statistics, 368 Research Bldg. Stop 6A2, 4400 University Drive, Fairfax VA 22030-4444 (LF)
WEIL, TIMOTHY (Mr.) SECURITYFEEDS, PO Box 18385, Denver CO 80218 (M)
WEISS, ARMAND B. (Dr.) 6516 Truman Lane, Falls Church VA 22043 (LF)
WERGIN, WILLIAM P. (Dr.) 1 Arch Place #322, Gaithersburg MD 20878 (EF)
WHITE, CARTER (Dr.) Naval Research Laboratory, Chemistry Division, 4555 Overlook Ave SW, Washington DC 20375 (M)
WIESE, WOLFGANG L. (Dr.) 8229 Stone Trail Drive, Bethesda MD 20817 (EF)
WILLIAMS, CARL (Dr.) 2272 Dunster Lane, Potomac MD 29854 (F)
WILLIAMS, E. EUGENE (Dr.) Dept. of Biological Sciences, Salisbury University, 1101 Camden Ave, Salisbury MD 21801 (M)
WILLIAMSON, TIMOTHY (Mr.) 1410 N. Scott St., Apt. 635, Arlington VA 22209 (M)
WITH, CATHERINE PO Box 6481, Silver Spring MD 20916 (M)
WITHERSPOON, F. DOUGLAS ASTI, 11316 Smoke Rise Ct., Fairfax Station VA 22039 (M)
WOOD, H. JOHN (Dr.) 15806 Pinecroft Lane, Bowie MD 20716 (M)
WOOTEN, RUSSELL (Mr.) 42508 DeSoto Terrace, Brambleton VA 20148 (M)
WULF, WILLIAM A. (Dr.) Quill Spring, 3897 Free Union Road, Charlottesville VA 22901 (F)
ZAMBRANO, ZACK STROCK (Mr.) 5000 Buena Vista Rd, Prince Frederick MD 20678 (M)
ZELKOWITZ, MARVIN (Dr.) 10058 Cotton Mill Lane, Columbia MD 21046 (M)

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